Process-based land-surface modelling at ECMWF: interactive versus modular scheme development?

Gianpaolo Balsamo
with support of several Colleagues at ECMWF

ABSTRACT:
Recent land surface developments at ECMWF have led to an improved representation of some of the physical processes occurring at the land-atmosphere interface, verified against a variety of independent observational sources. In particular, a **MODIS-based leaf-area-index** climatology, which describes the seasonal evolution of vegetation, has replaced a fixed-in-time vegetation, and a revised bare-soil evaporation has introduced a larger extraction of superficial water in non-vegetated area. These two schemes revisions are shown to improve near-surface temperatures and soil moisture simulations.
In an attempt of moving towards interactive ecosystems, a photosynthesis-based module has also been introduced in order to simulate **natural CO2 emissions over land**. However, the land-carbon parameterization does not interact yet with the evapotranspiration formulation, and similarly, the vegetation seasonality representation does not interact with the momentum budget. These **"ad-hoc" separations of processes** have a practical advantage of **modularizing the model development** (particularly useful in community models) but may present some caveats of realism when representing naturally inter-dependent processes occurring in the Earth system. Examples from recent simulations will be used to illustrate this paradigm and the problems associated to full-coupling between processes.

Outline

- Introduction: model development in NWP & Climate
- Land surface evolution and current status
- Natural biosphere CO2 uptake in NWP framework
- Ongoing land research
- Conclusions

Developments in Weather & Climate models

The Earth surface model developments in NWP and Climate science differ in a number of aspects:

Main Drivers: *Meteorological Users driven* ***vs***

Climate-Change-Science driven

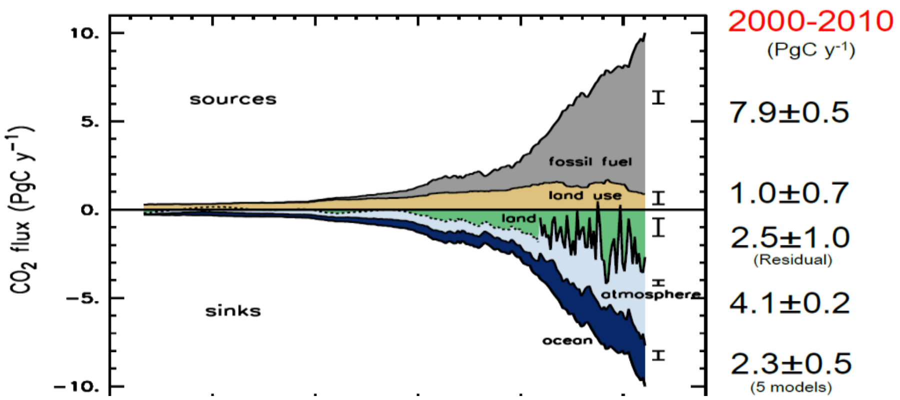
Constraints: *NWP systems have to be limited in complexity for timely daily production* ***vs***

Climate systems have to Include most of the relevant processes

(bio-physical but also bio-geo-chemical processes and complex feedbacks)

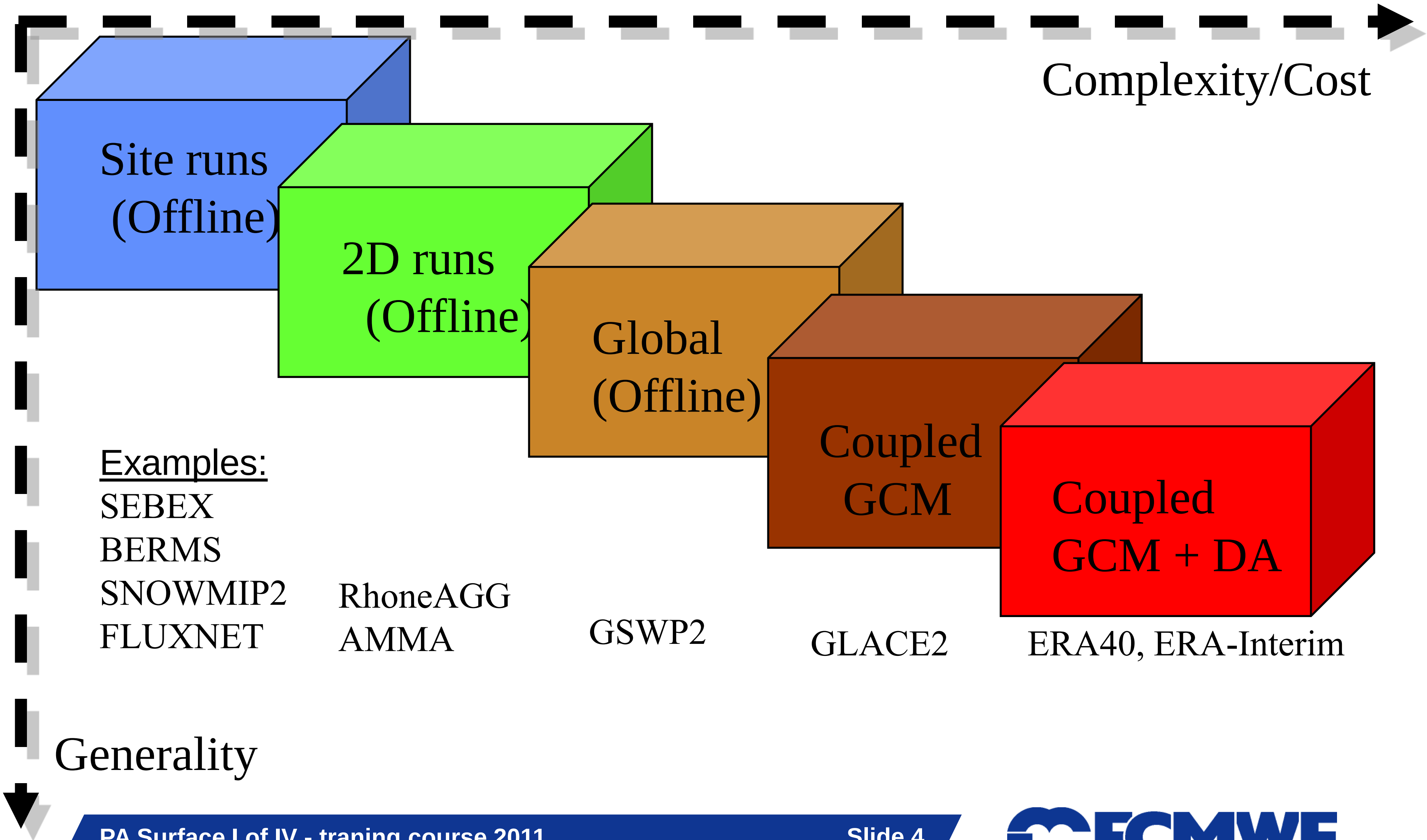
Accuracy requirements: *diurnal-to-synoptic timescale everywhere and with DA support* ***vs***

global annual trends in recent history



Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS

Strategy for land surface model development at ECMWF



ECMWF

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Land Surface Model evolution

2000/06	2007/11	2009/03	2009/09		2010/11

- **TESSEL**

  Van den Hurk et al. (2000)
  Viterbo and Beljaars (1995),
  Viterbo et al (1999)

  Up to 8 tiles (binary Land-Sea mask)

  GLCC veg. (BATS-like)

  ERA-40 and ERA-I scheme

- Hydrology-**TESSEL**

  Balsamo et al. (2009)
  van den Hurk and
  Viterbo (2003)

  Global Soil Texture (FAO)

  New hydraulic properties

  Variable Infiltration capacity & surface runoff revision

- **NEW SNOW**

  Dutra et al. (2010)

  Revised snow density

  Liquid water reservoir

  Revision of Albedo and sub-grid snow cover

- **NEW LAI**

  Boussetta et al. (2011)

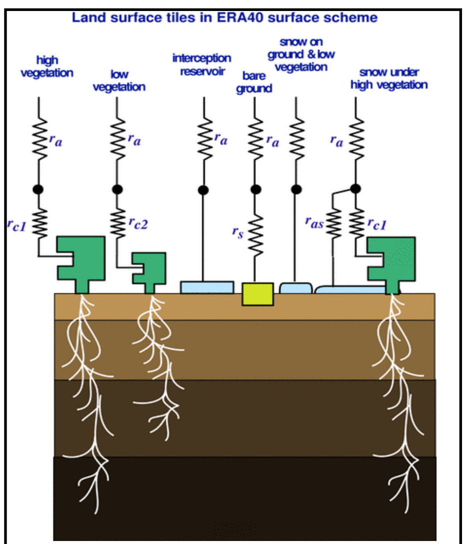
  New satellite-based

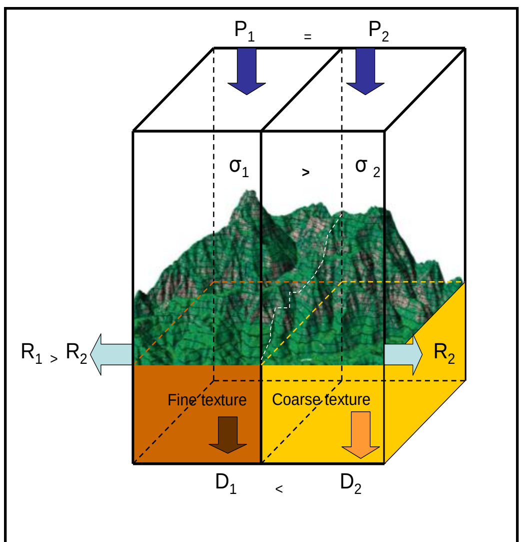
  Leaf-Area-Index

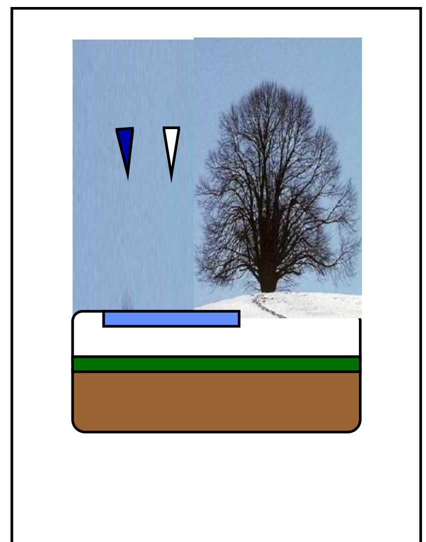
- **SOIL Evaporation**

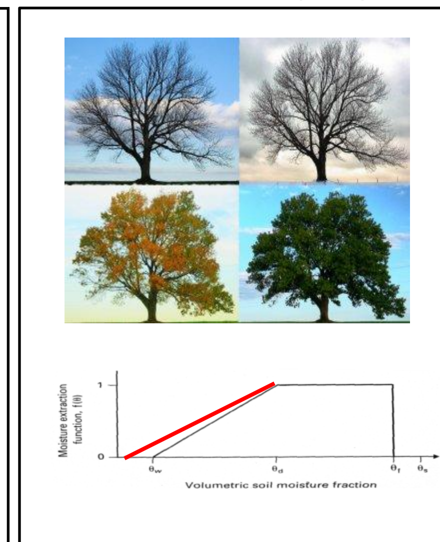
  Balsamo et al (2011) based on

  Mahfouf Noilhan (1991)









Land Data Assimilation system evolution

1999/07	2004/03	2010

- **OI screen level analysis**

  Douville et et al. (2000)

  Mahfouf et al. (2000)

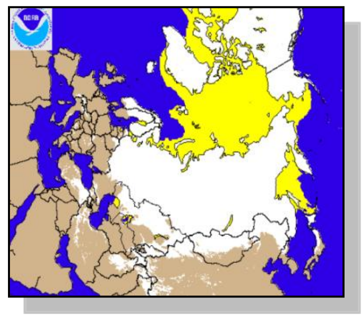
  Soil moisture analysis based on Temperature and relative humidity analysis

- **Revised snow analysis**

  Drusch et al. (2004)

  Cressman snow depth analysis using SYNOP data

  Improved by using NOAA / NSEDIS Snow cover extend data



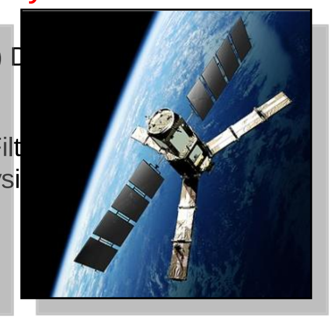
- **NEW EKF Soil Moisture analysis**

  Drusch et al. (2009) De Rosnay et al. (2011)

  Extended Kalman Filter developed for soil moisture analysis

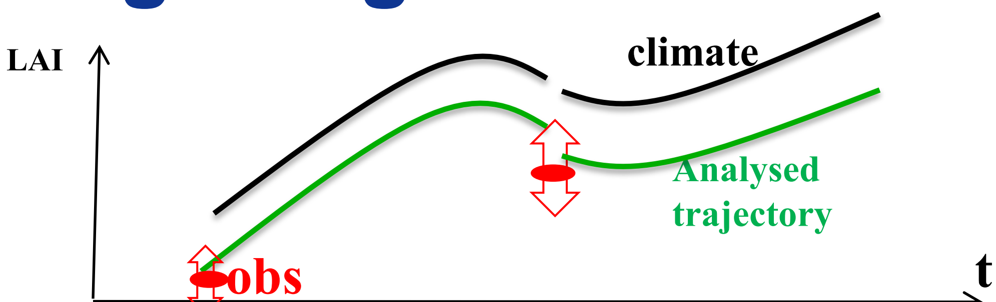
- **NEW OI Snow analysis**

METOP-ASCAT



SMOS

Integrating Leaf Area Index **(in progress)**

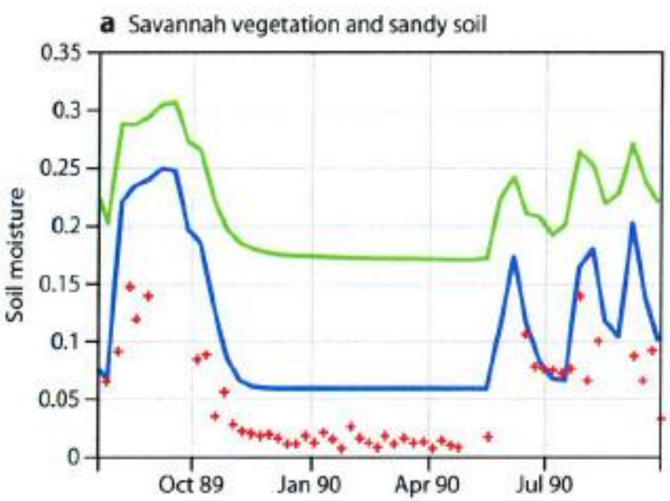


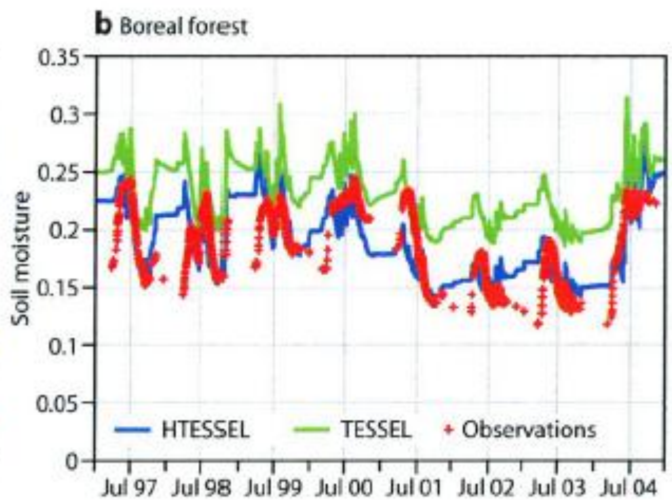
- **LAI univariate analysis**

  Exploratory study in Jarlan et al. (2009)

  Developed within GEOLAND2 following Gu et al. (2006)

Soil hydrology
(Balsamo et al. 2009, JHM)





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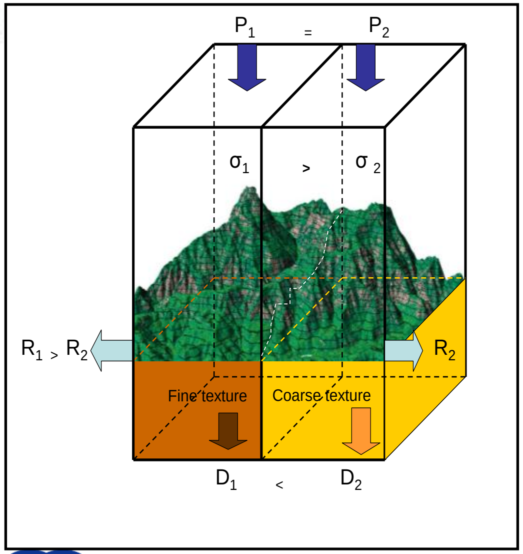
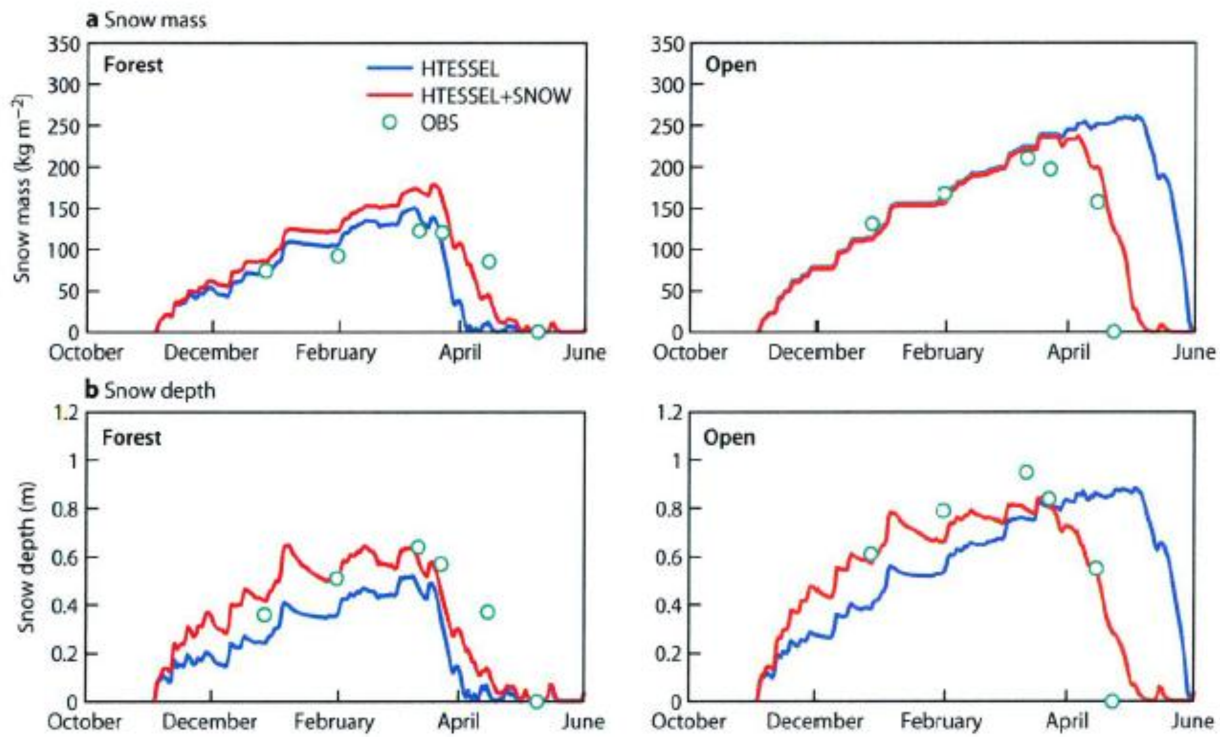


New snow scheme

(Dutra et al. 2010, JHM)



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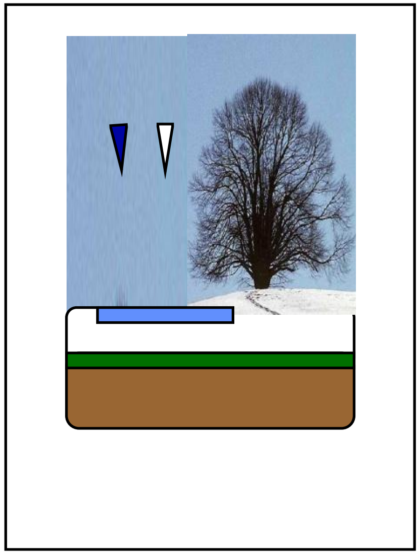
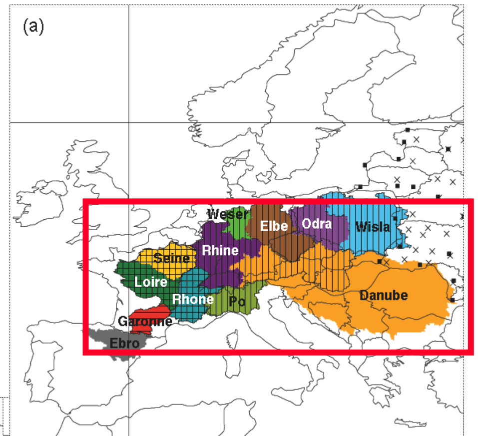


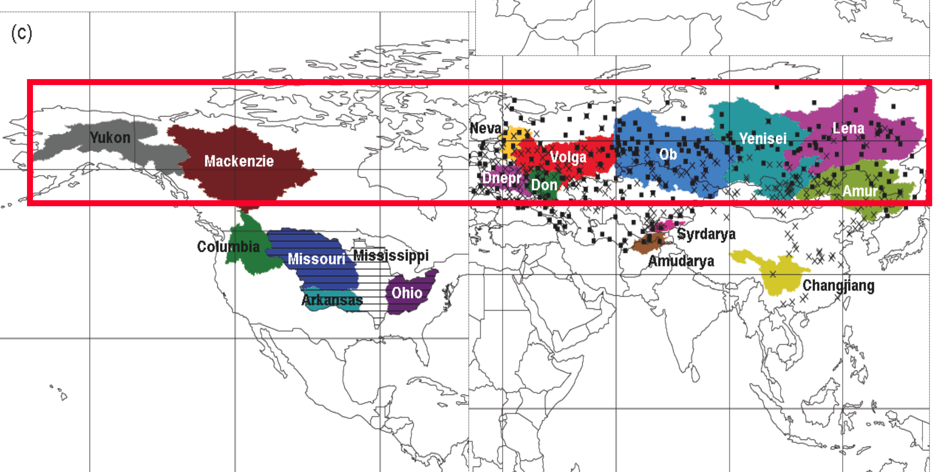
Assessing impact on hydrological cycle

In Collaboration with M. Hirschi (ETH-Zurich)

ECMWF Newsletter No. 127 – Spring 2011

In collaboration with ETH-Zurich, see also: Hirschi et al. 2006, J. Hydromet., 7(1), 39-60





Parametrization scheme	Runoff RMSE (mm/day)	Observed area-weighted average runoff from GRDC (mm/day)
Area-weighted average of snow-free basins (~1,632,601 km^2): Northeast-Europe and Central-Europe		
TESSEL	0.28	0.76
HTESSEL	0.17	
Area-weighted average of snow basins (~12,334,161 km^2): Yukon, Podka., Lena, Tom, Ob, Yenisei, Mackenzie, Volga, Irtish and Neva		
HTESSEL	0.75	1.96
HTESSEL+SNOW	0.51	

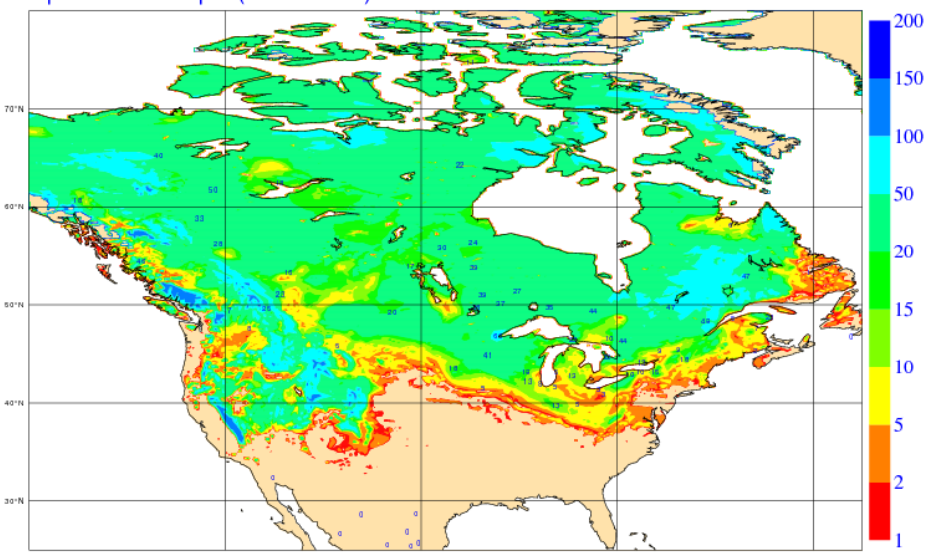
Table 1 Runoff root-mean-square error (RMSE) for GSWP2 from global offline simulations (1986–1995) verified with GRDC observations on snow-free basins for TESSEL, HTESSEL, and snow-dominated basins for HTESSEL, HTESSEL+SNOW.

Using an equal forcing (this time based on ERA40GPCP corrected forcing) TESSEL and the new land surface model version currently operational can be evaluated against river discharges of main Northern Hemisphere river at monthly timescales (no routing). New activities with river-routing schemes can assess hydrological impact on daily timescale (Pappenberger et al.)

Snow verification US (Winter 2010-2011)

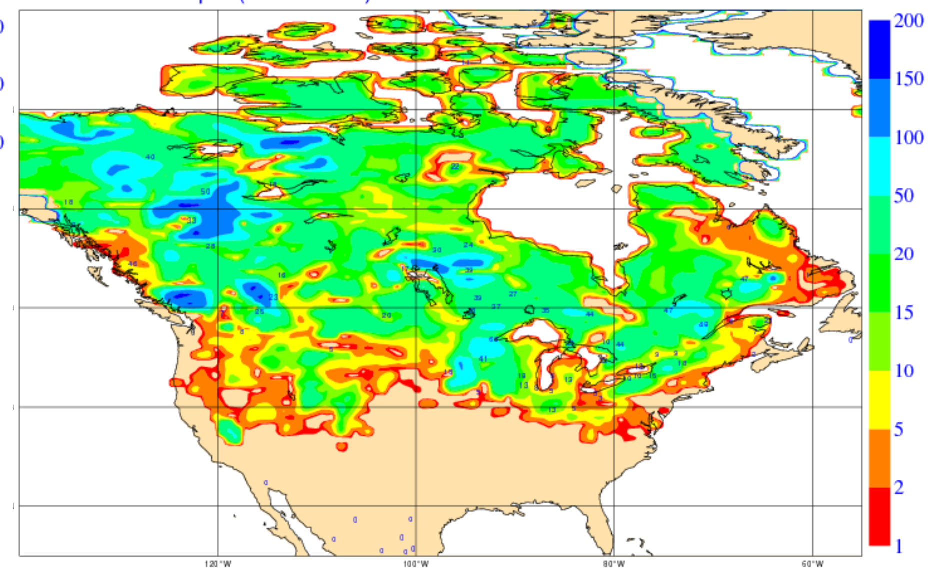
Operational-suite

Oper SNOW Depth (cm of snow) vs. SYNOP observations 20101223 at 6UTC



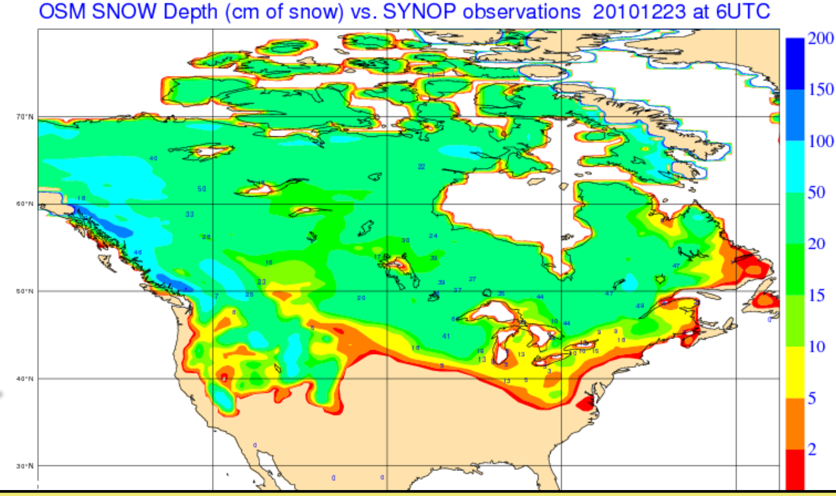
ERA-Interim

ERA-I SNOW Depth (cm of snow) vs. SYNOP observations 20101223 at 6UTC



New Land EI-forced

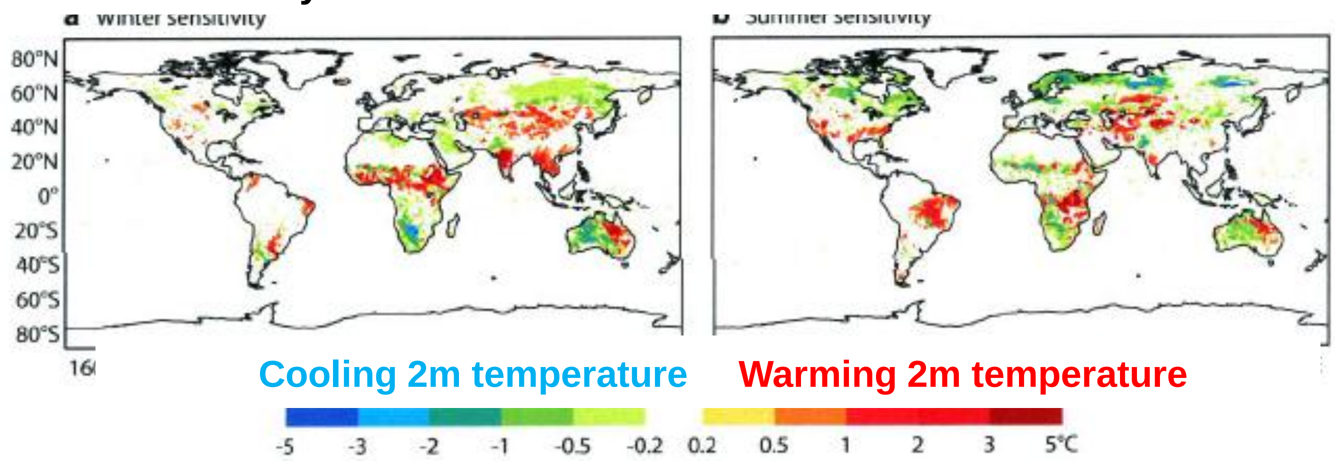
OSM SNOW Depth (cm of snow) vs. SYNOP observations 20101223 at 6UTC



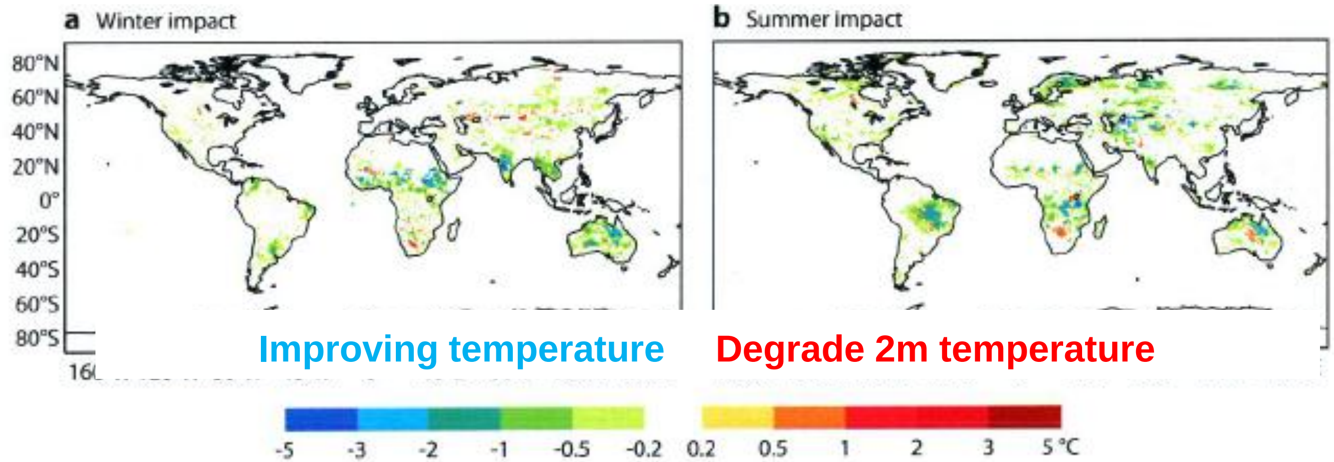
Operational snow analysis (de Rosnay et al., 2011) has been greatly improved and there is consistency to the OSM-EI output. EI is also improved w.r.t. 2009 for geolocation of NESDIS snow data. Cressman is shown to be linked to Pacman snow feature

Forecasts sensitivity and impact

Forecast sensitivity



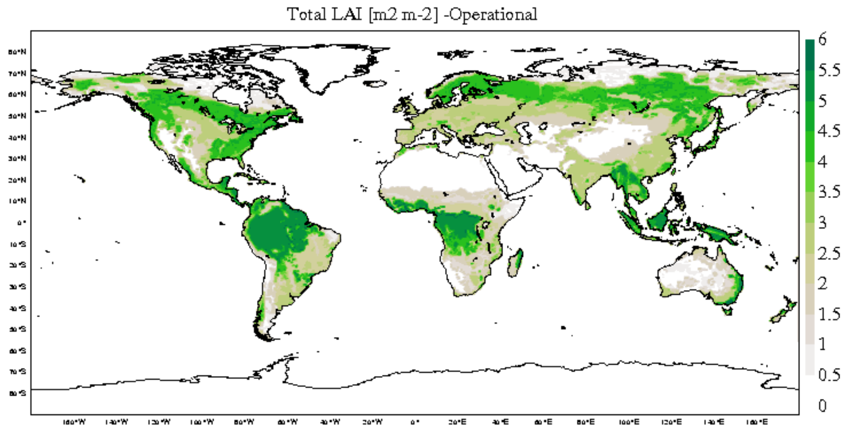
Forecast Impact



The revised soil/snow scheme introduce additive improvements respectively in summer/winter seasons forecasts of 2m temperatures

New vegetation seasonality

(Boussetta et al. 2011, IJRS)



Previous LAI (van den Hurk et al. 2000, ECMWF TM295)

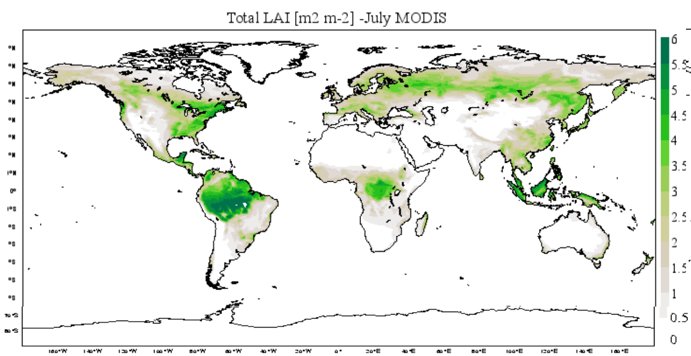
- **NEW LAI**

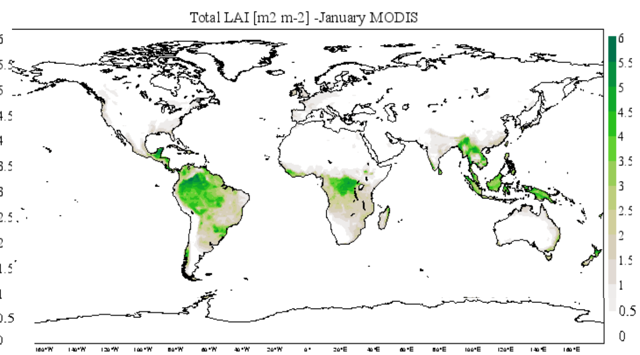
  Boussetta et al. (2011)

  New satellite-based

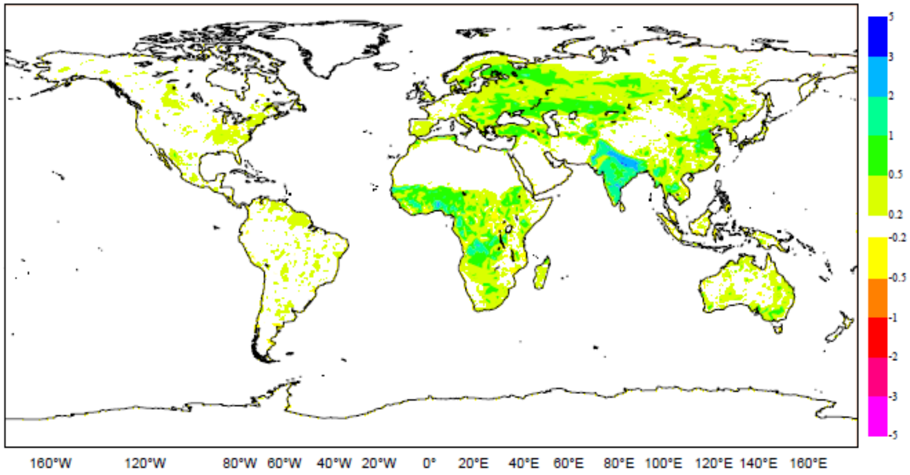
  Leaf-Area-Index

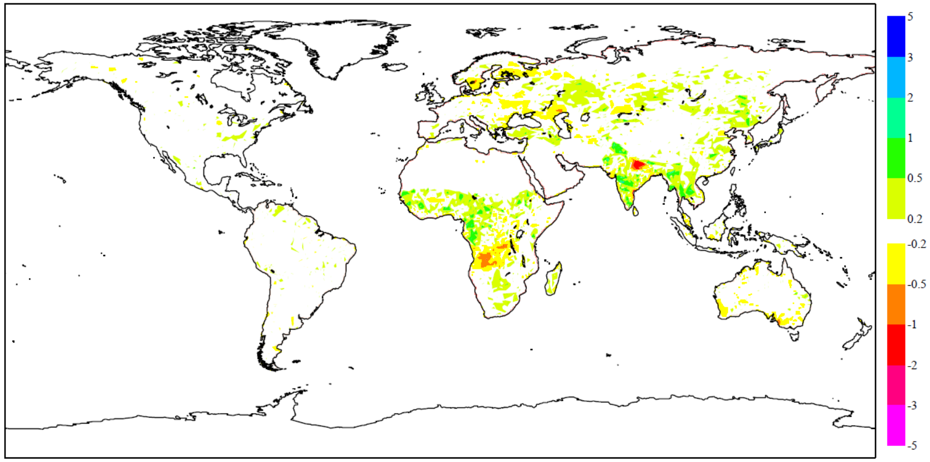
MODIS LAI (c5) Myneni et al., 2002, Jarlan et al. 2009





Impact of the usage of the MODIS based monthly LAI climatology on the 2m Temperature





Sensitivity
(warming)

$$Sensitivity(T) = T_{MLAI} - T_{ctl}$$

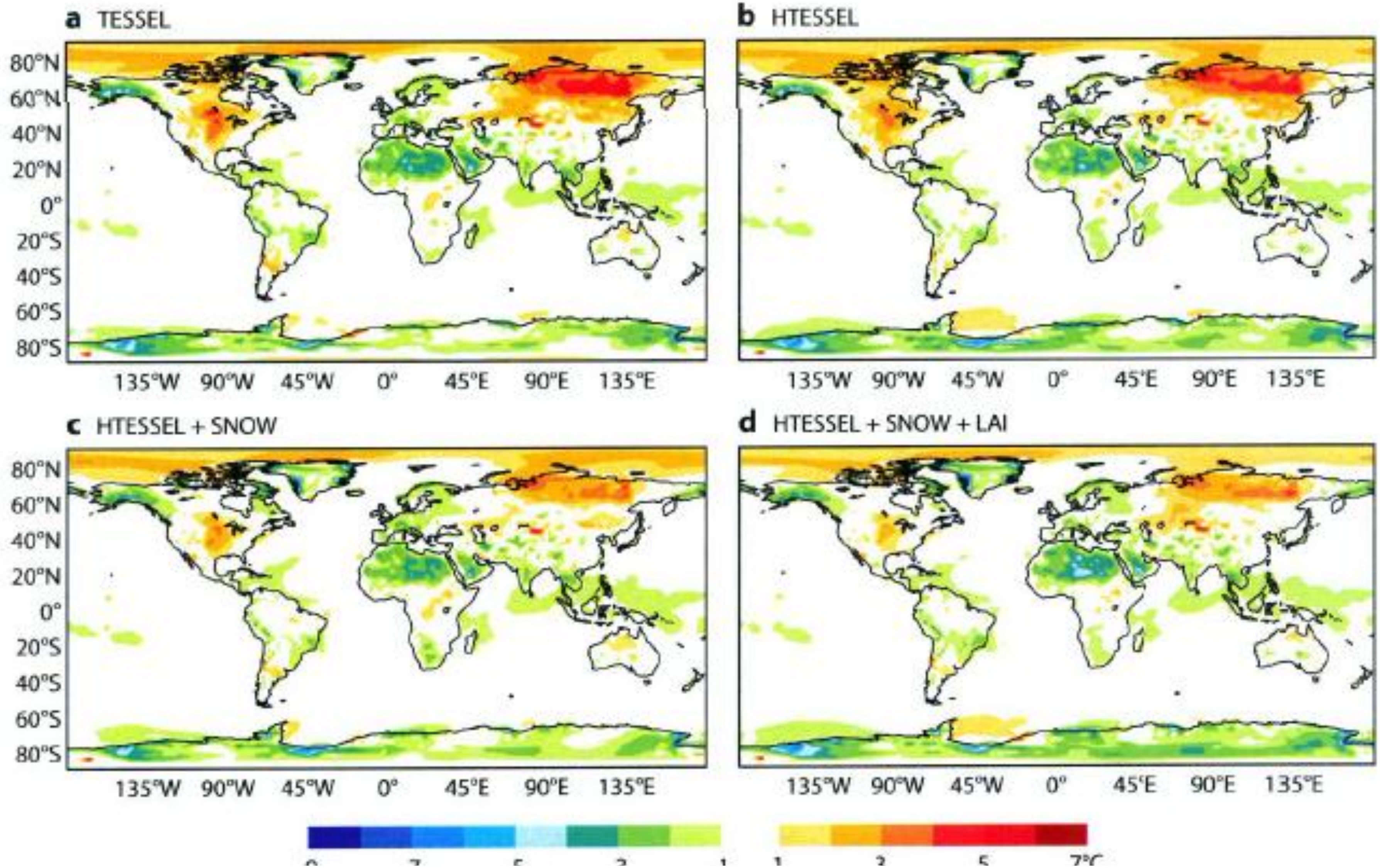
Impact
(error reduction)

$$Impact(T) = |T_{ctl} - T_{an}| - |T_{MLAI} - T_{an}|$$

Results from forecast experiments using MODIS LAI relative to the fixed LAI case for MAM at FC+36 (valid 12UTC), 2m temperature [K]

Climate simulations: the impact of land

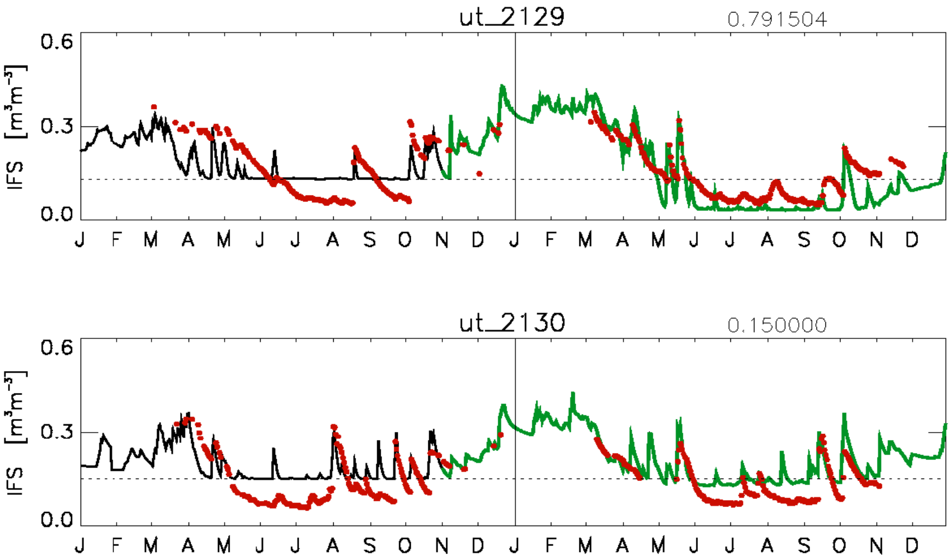
Hindcasts, 4-member 13-month temperature difference



simulations colder than ERA-Interim Warmer than ERA-Interim

New bare soil evaporation

Albergel et al. 2012, in preparation



ut_2129
####2010###
R = 0.583
Bias = 0.005
RMSD= 0.068

####2011###
R = 0.906
Bias = 0.033
RMSD= 0.056

ut_2130
####2010###
R = 0.685
Bias = -0.036
RMSD= 0.064

####2011###
R = 0.812
Bias = -0.037
RMSD= 0.052

- **SOIL Evaporation**

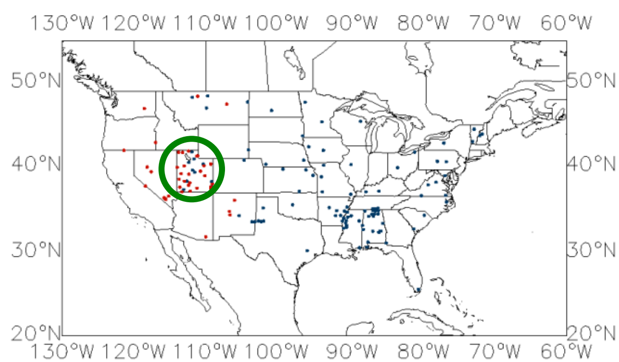
Balsamo et al. (2011)

based on

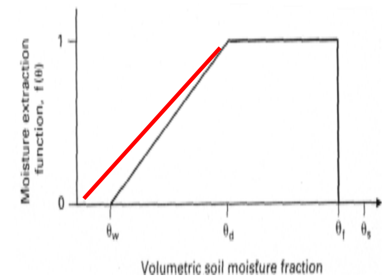
Mahfouf and Noilhan (1991)

The introduction of bare ground evaporation revision (green-line) is quite effective in reducing the soil moisture below the wilting point in non-vegetated area (upper panel of figure above, at 79% bare ground, SCAN site in Utah).

$R_c = R_{soil} f_2(w_1)$



$f_2(w_1)$



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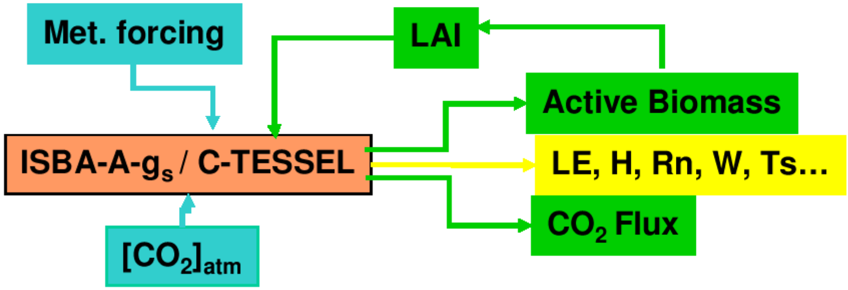
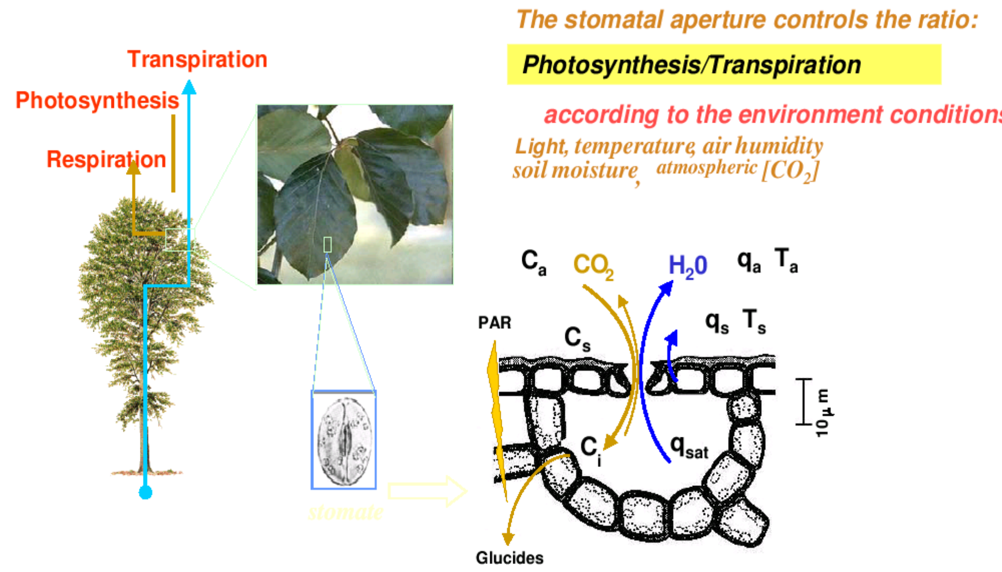
Land carbon/photosynthesis-based parameterisation (CTESSEL)

(Boussetta et al. 2012, in preparation)



$$A_n = \frac{\alpha}{r_{cc}}(C_s - C_i)$$

$$E = \frac{\beta}{r_c + r_a}(q_a - q_{sat}), r_c = f(r_{cc})$$



CTESSEL combines HTESSEL (Balsamo et al. 2009) with the A-gs model used within the ISBA-Ags (Calvet et al.1998) and developed by Jacobs et al. (1996);

➔Account for the effect of CO2 concentration and the interactions between all environment factors on the stomatal aperture.

➔Replaces the Jarvis-type stomata conductance by a **photosynthesis dependant-type stomata conductance** (Jacobs et al.1996)

➔The model can account for the vegetation response to the radiation at the surface, temperature, soil moisture, temp stress

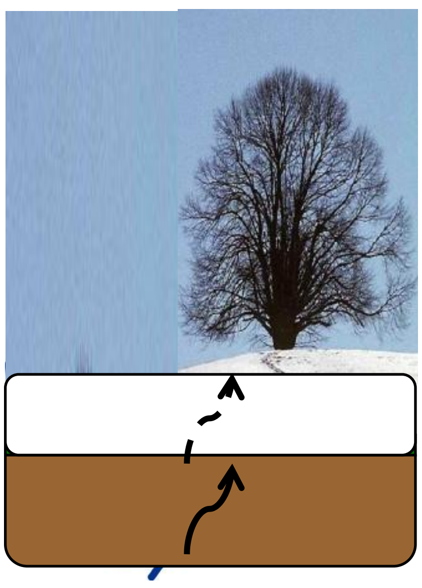
➔Vegetation Assimilation of CO2 can be used to drive a vegetation growth module to simulate LAI

➔The Ecosystem Respiration is parameterized as a function of soil temperature, and soil moisture and biome type via a reference respiration parameter

Soil Respiration improvement for winter season (1)

$$\boxed{R_{soil} = R_0 Q_{10}^{(0.1(T_{soil}-25))} f_{sm}}$$

$$R_{soil} = R_0 \boxed{e^{-\alpha . Z_{snow}}} Q_{10}^{(0.1(T_{soil}-25))} f_{sm}$$



Including a snow attenuation effect on the soil CO2 emission

Preliminary test in atmospheric coupled MACC model including CO2 contributed to identify a relevant process to be represented in order to adjust the contribution from the surface

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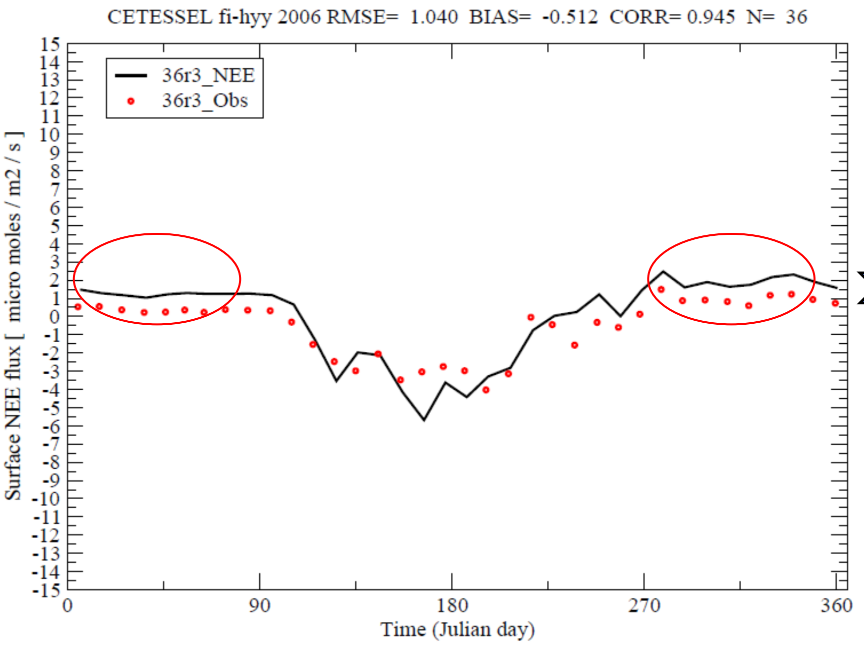
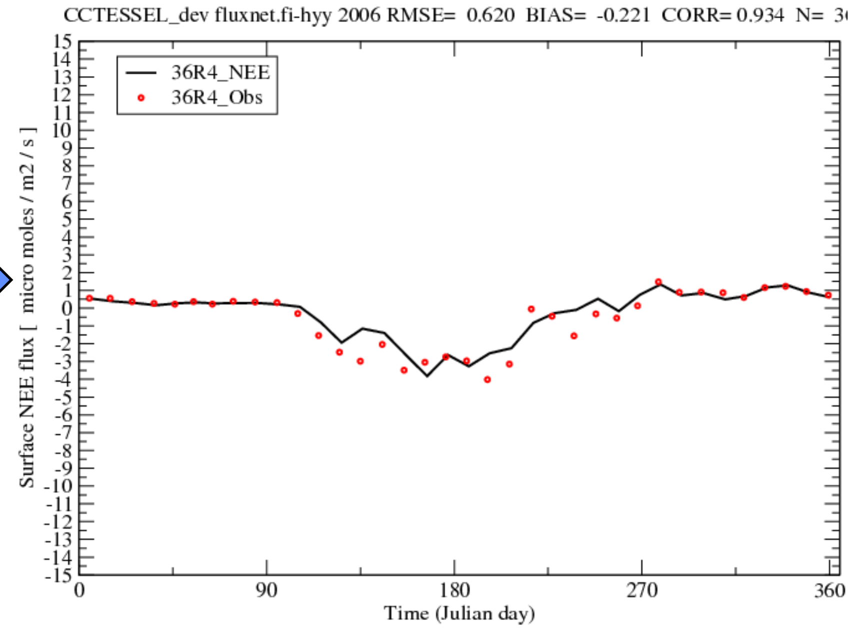
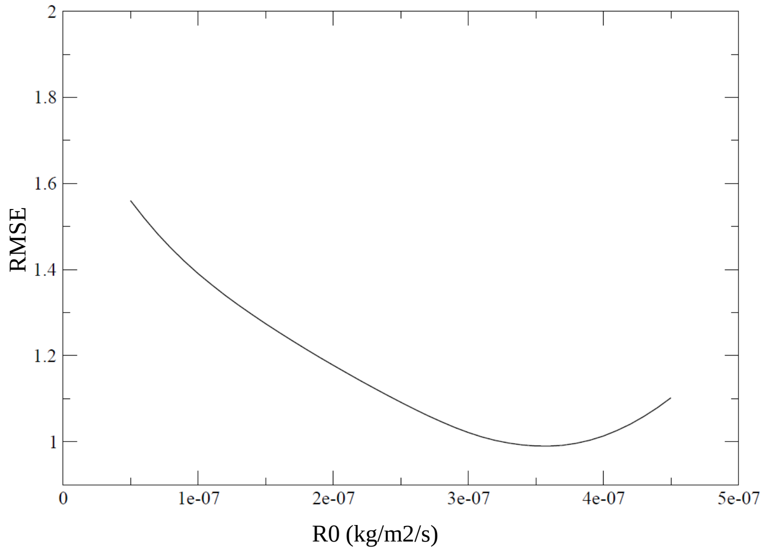
Soil Respiration improvement for winter season (2)



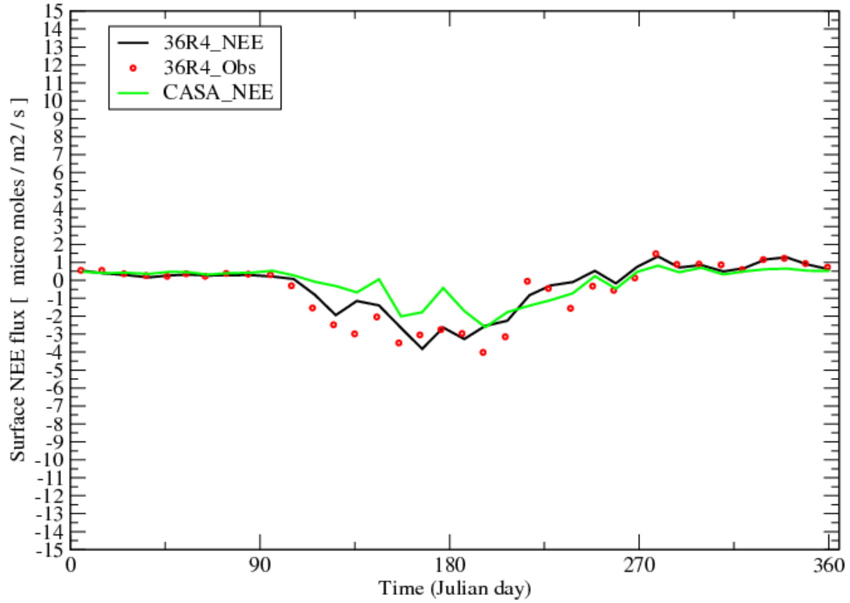


Example of NEE (micro moles /m^2/s) predicted over the site Fi-Hyy taking the cold process into account (right) and previous simulation (left) by CTESSEL (black line) and observed (red dots)

Optimization of CTESSEL parameters by vegetation types



Example of R0 optimization for the Evergreen Needleleaf Forest



Example of NEE (micro moles /m^2/s) predicted over the site Fi-Hyy by CTESSEL (black line) and CASA-GFED3 (green-line)

Scheme	GPP rmse	GPP bias	GPP corr	NEE rmse	NEE bias	NEE corr	Reco rmse	Reco bias	Reco corr
CTESSEL	7.936	-6.224	0.743	3.736	-1.656	0.536	5.422	4.625	0.724
CASA	-	-	-	1.872	0.739	0.297	-	-	-

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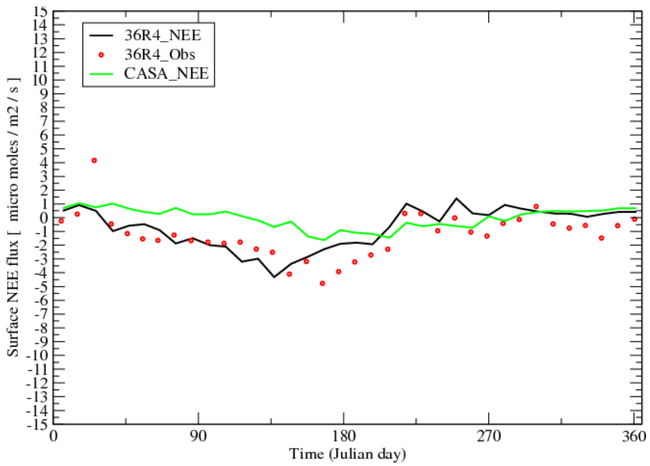
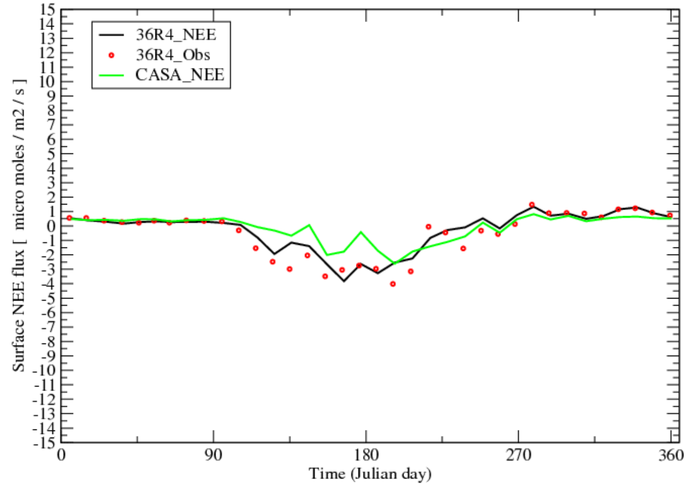
Improved Skill in simulating Net Ecosystem Exchange (1)

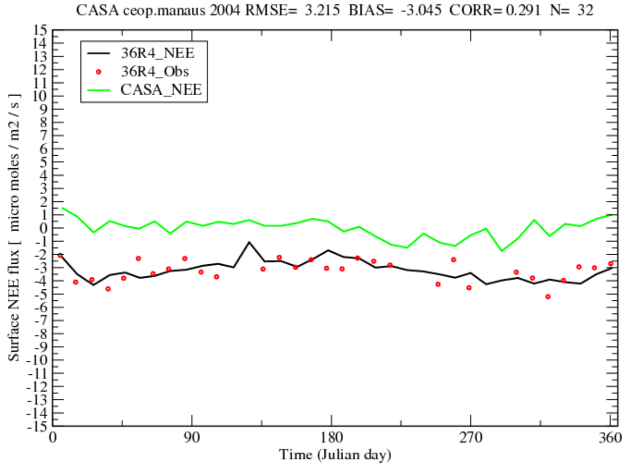


NEE for Two European sites



Example of NEE (micro moles /m^2/s) predicted over the site **Fr-LBr**(left) and **Fi-Hyy** (right) by **CTESSEL** (black line) and **CASA-GFED3** (green-line)

NEE for Amazon site (Manaus)



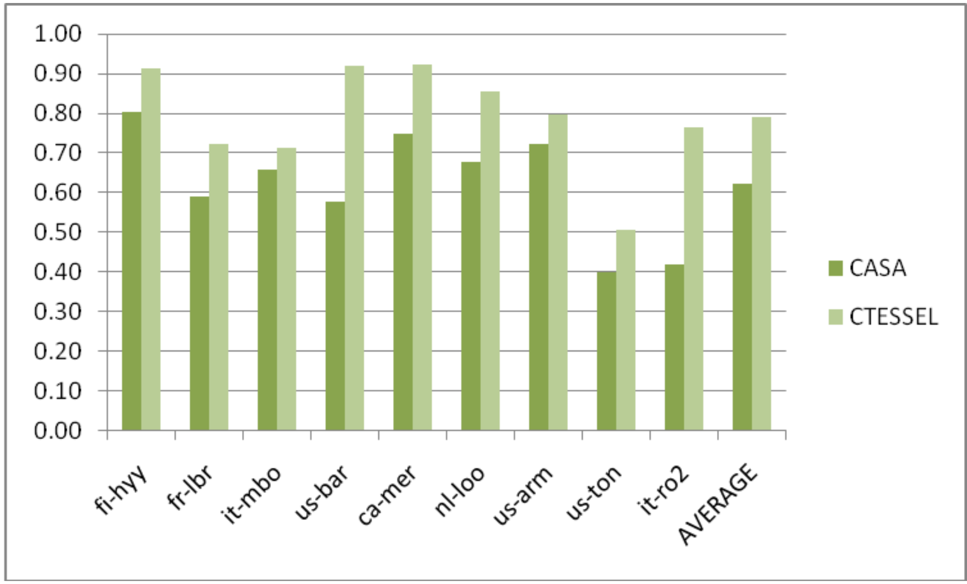
Example of NEE (micro moles /m^2/s) predicted over the Manaus tropical site by **CTESSEL** (black line) and **CASA-GFED3** (green-line)

ECMWF

Improved Skill in simulating Net Ecosystem Exchange (2)

Country	Flux-tower Site	Vegetation Type
Finland	fi-hyy	Evergreen Needleleaf Forest
France	fr-lbr	Evergreen Needleleaf Forest
Italy	it-mbo	Grassland
USA	us-bar	Deciduous Broadleaf Forest
Canada	ca-mer	Deciduous Broadleaf Forest
Netherland	nl-loo	Evergreen Needleleaf Forest
USA	us-arm	Crops
USA	us-ton	Woody Savannas
Italy	it-ro2	Deciduous Broadleaf Forest

List of sites used for the verification of NEE fluxes of the updated CTESSEL scheme (model assigned physiography)

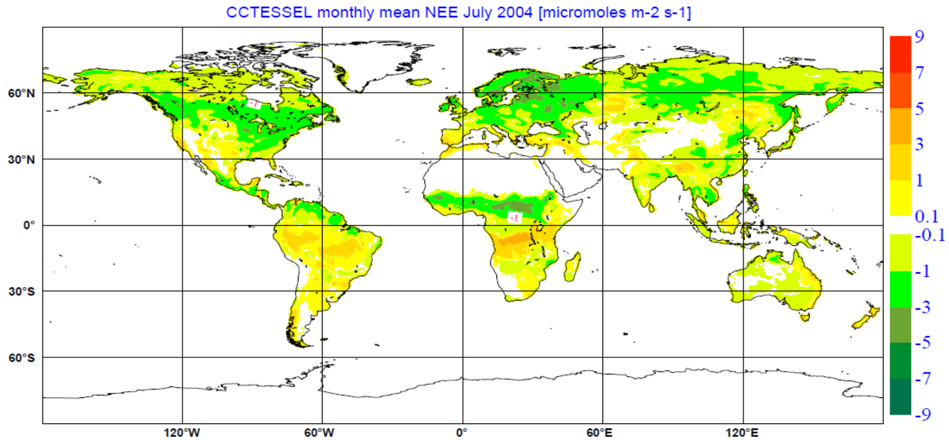


Correlation of modelled and observed NEE for CASA-GFED3 and for CTESSEL over 9 sites with different dominant biomes

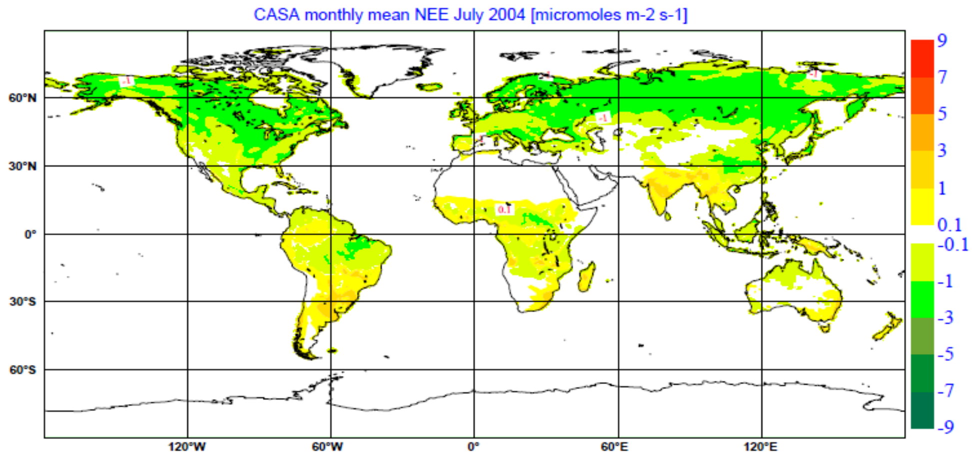
➔After the redefinition of vegetation dependent parameters in CTESSEL and the Inclusion of snow and cold temperature attenuation effects on land carbon emission, => CTESSEL is outperforming CASA-GFED3 on most of the nothern-hemisphere and tropical stations with the 1-D offline simulation.

Comparing with State-of-the-art global natural carbon dioxide

CTESSEL



CASA

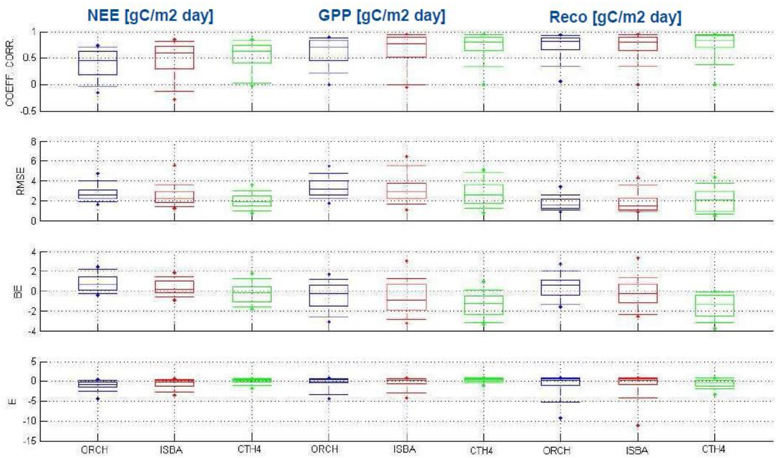


- similar patterns over the northern hemisphere
- CTESSEL has more spatial variability than CASA due to its link with meteorological forcing

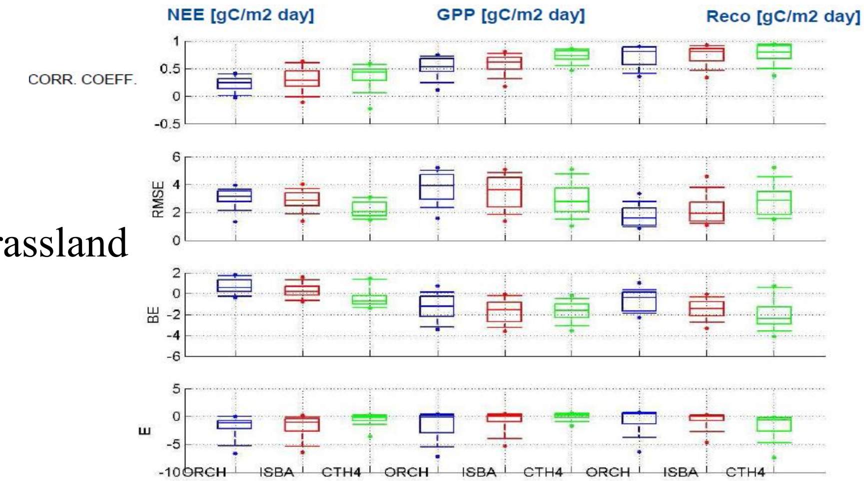
Independent Validation of CTESSEL

Courtesy from M. Balzarolo, (UNITUS, Italy)

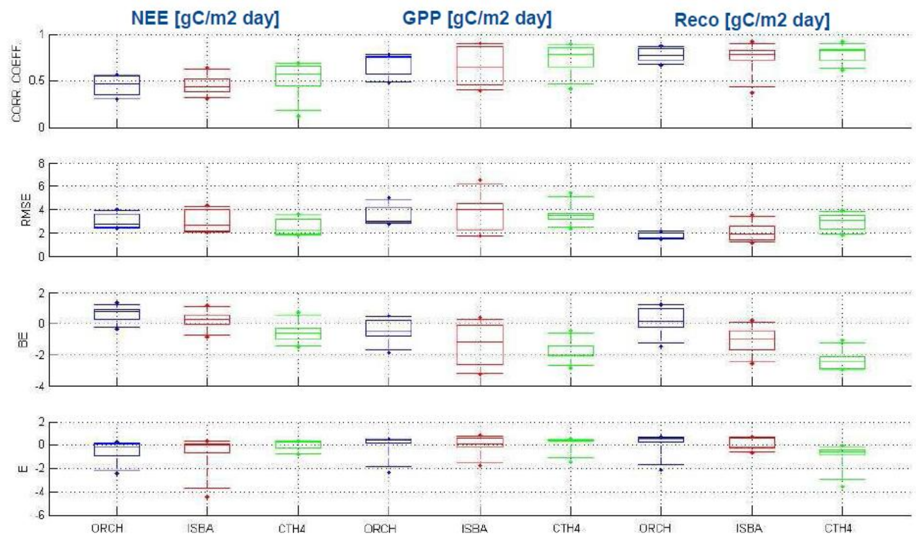
Forest



Grassland



Cropland

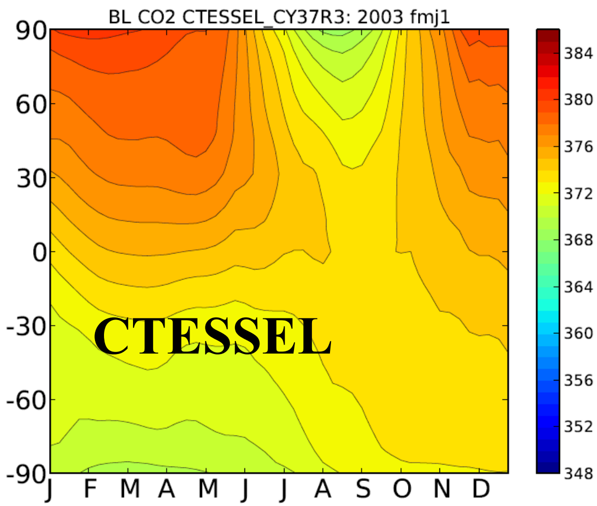


CTESSEL in green
ORCHIDEE in BLUE
ISBA-Ags in red

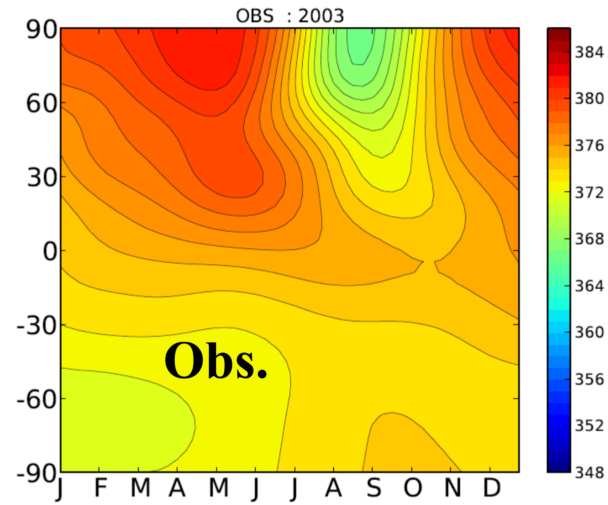
➔With the 1-D offline simulation forced by ERA-Interim CTESSEL is outperforming ORCHIDEE and ISBA-Ags on most of the European stations for different biomes.

Land Carbon improved feedback to the atmospheric CO2:

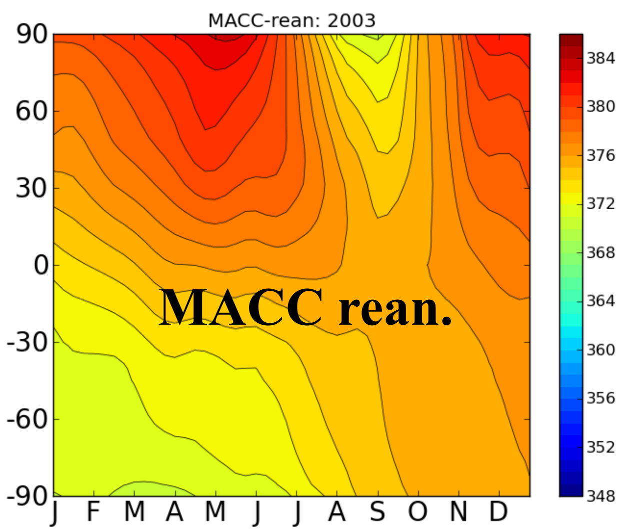
Hovmoeller of CO2 seasonal cycle - collaboration with MACC (A. Agusti-Panareda)



Based on CO2 fluxes CTESSEL improved version outputs

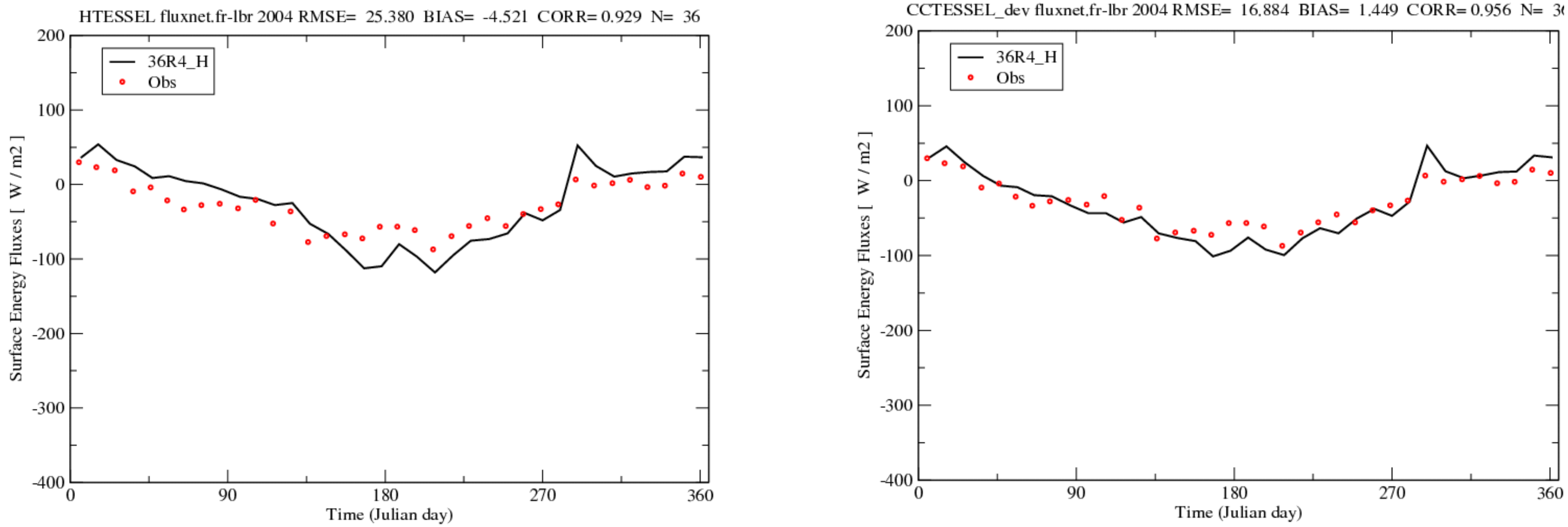


Based on processed marine BL observations (NOAA Globalview product)

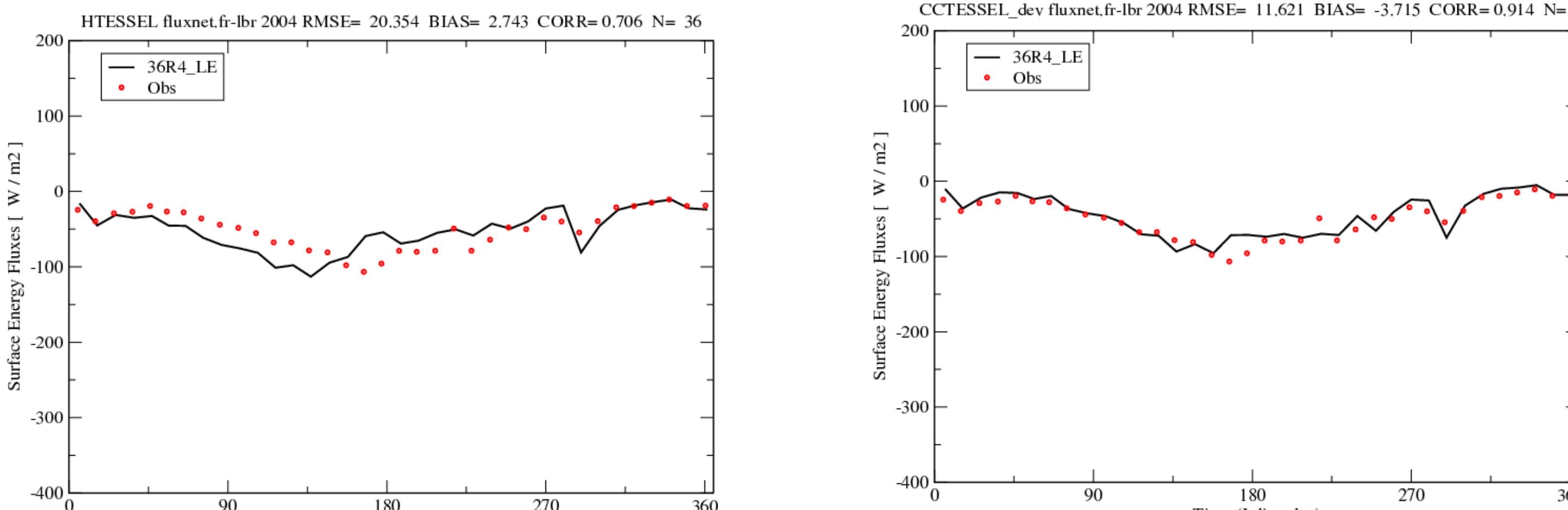


Based on CO2 fluxes from CASA-GFED3 outputs

LE/H: CTESSEL vs HTESSEL (operational)



Surface sensible heat flux (W/m^2) compared with flux-tower observations over Fr-LBr for HTESSEL (left panel) and CTESSEL (right panel)

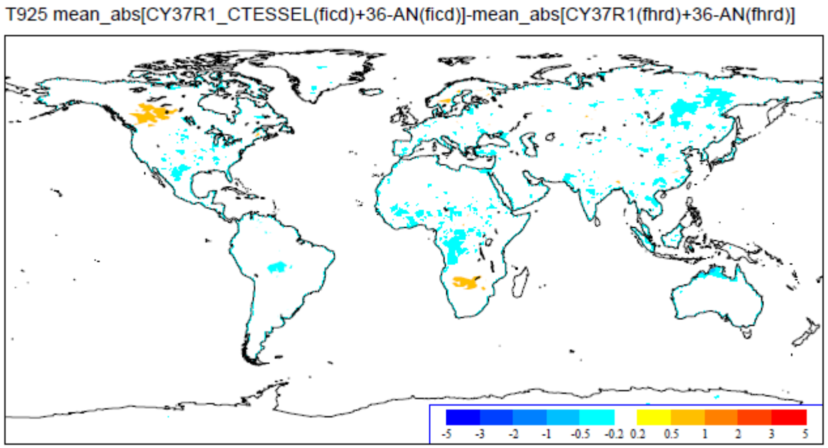


Surface laten heat flux (W/m^2) compared with flux-tower observations over Fr-LBr for HTESSEL (left panel) and CTESSEL (right panel).

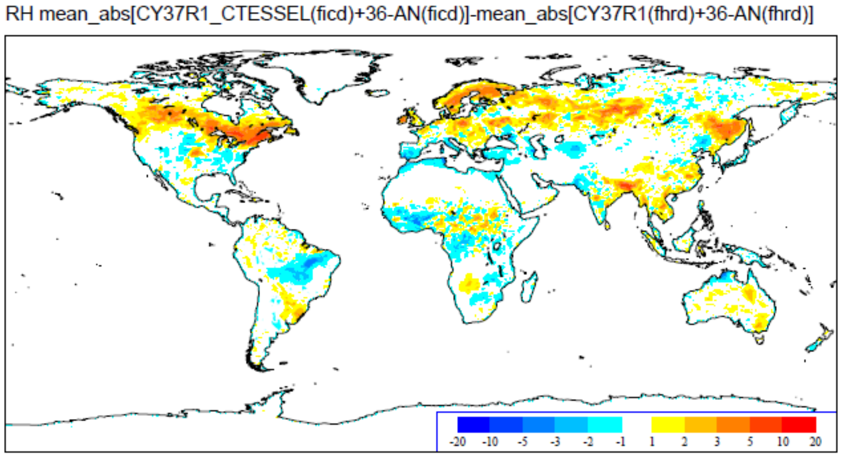
CTESSEL improves the LE/H simulations (Jacobs vs Jarvis approach) therefore it has potential to improve weather forecasts…but

LE/H: Interaction with the atmosphere

2m T Error differences from the CTL



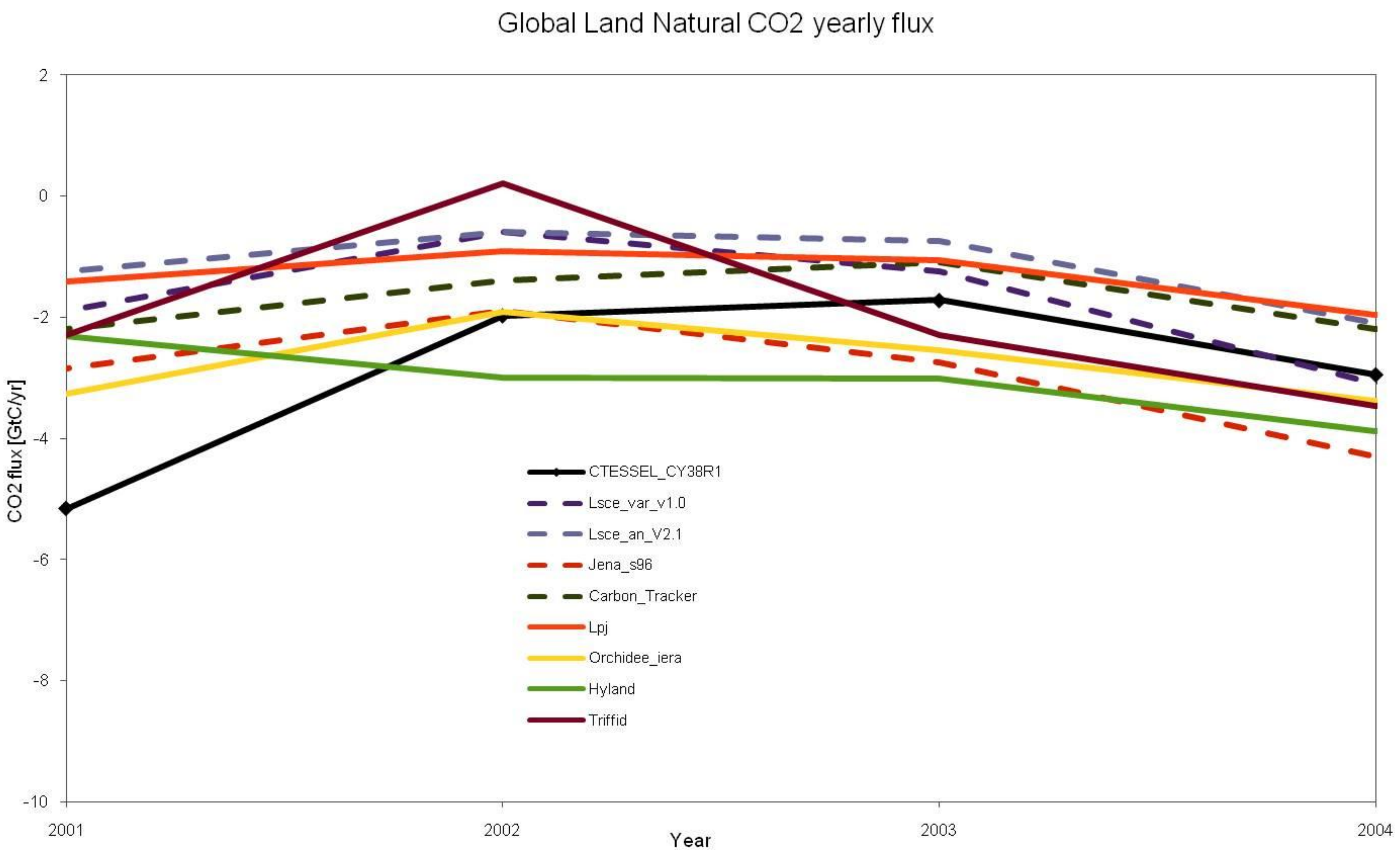
2m Rh Error differences from the CTL



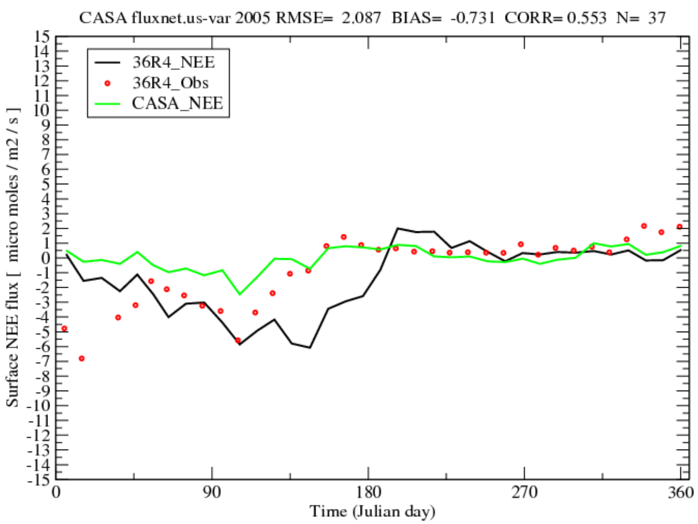
Having better LE/H heat flux from the surface (offline) does not always lead to a better atmospheric prediction ➔ interaction with other processes and compensating errors?

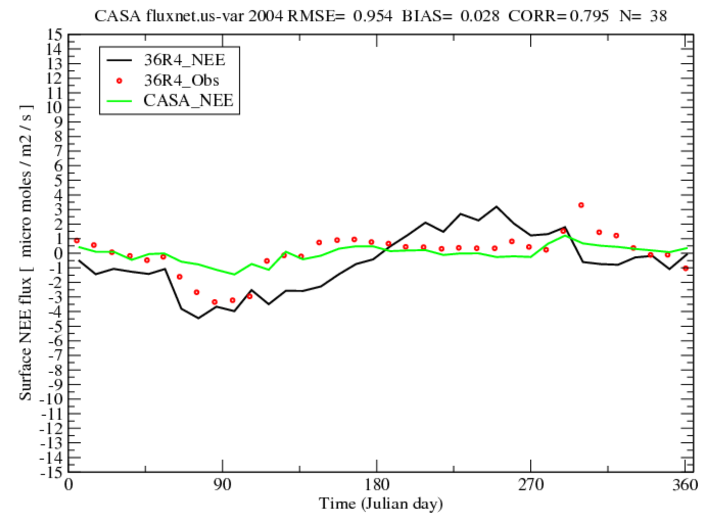
A pragmatic solution is to keep separate the conductances calculation (CTESSEL has therefore neutral impact onto the LE/H)

Global Natural land CO2 budget



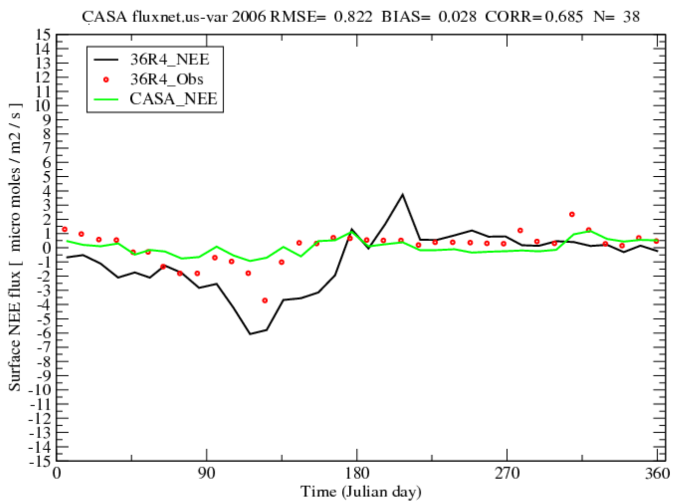
Current shortcomings: LAI variability?





Comparison of 3 different years show the current shortcoming of the use of LAI climatology => presence of large interannual variability? Harvest period not matched?

NEE (micro moles /m^2/s) predicted over the site US-Var by **CTESSEL** (black line) and **CASA** (green-line)

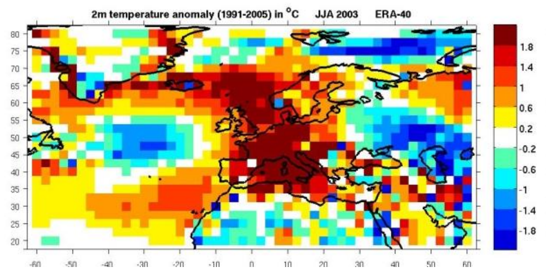


Impact of climate anomalies on CO_2 flux: The summer 2003

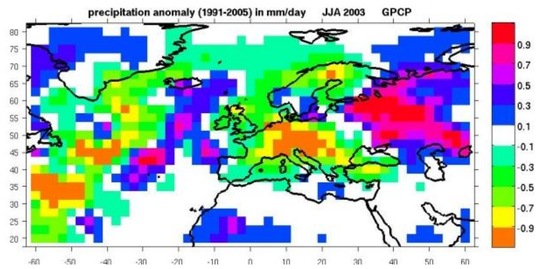
- Summer 2003 heat-wave/drought hitting western Europe. The effect on NEE was to turn land into a CO_2 source due to vegetation stress conditions, consistently with findings of P. Ciais et al. (2005, Nature)

Observed anomaly

2m temp

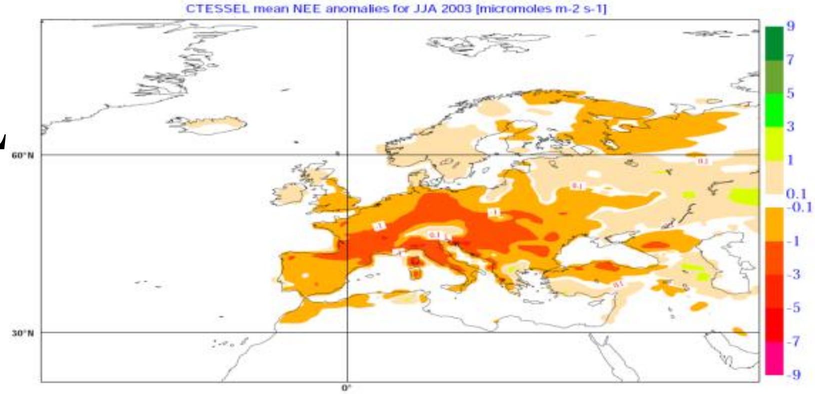


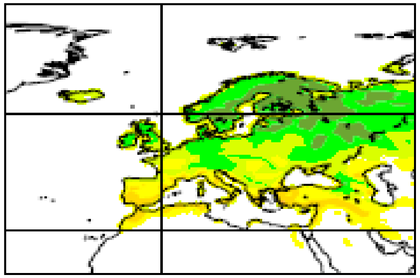
precipitation



NEE

CTESSEL model anomaly

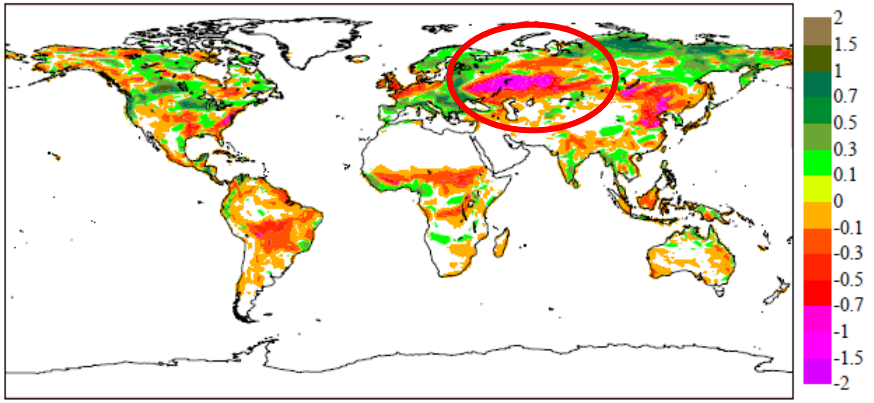




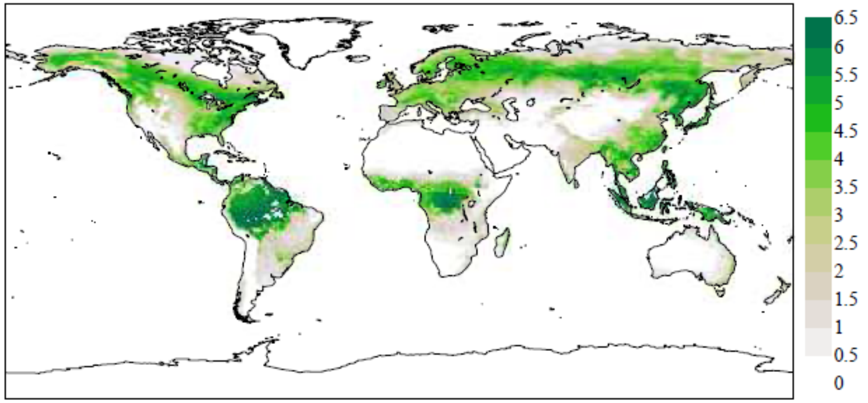
July 2004 shown for comparison

LAI and CO2 flux inter-annual variability: The summer 2010 Russian case

CTESSEL Leaf Area Index anomaly from 1979-2010 mean [m2/m2] for 201007

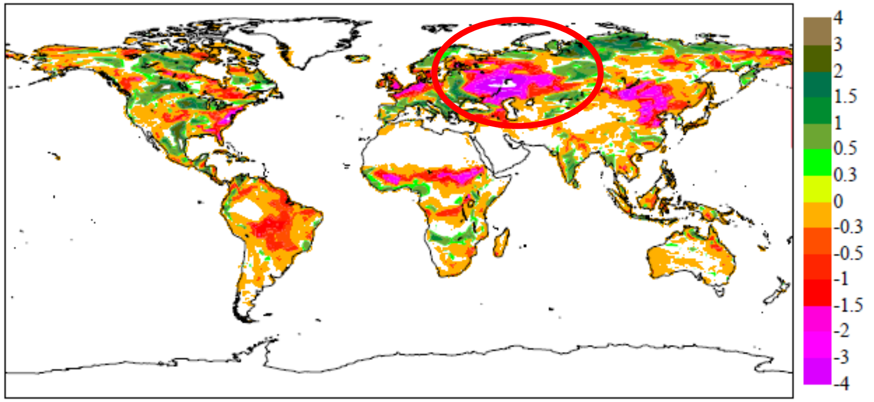


CTESSEL 1979-2010 monthly mean Leaf Area Index [m2/m2] for 07

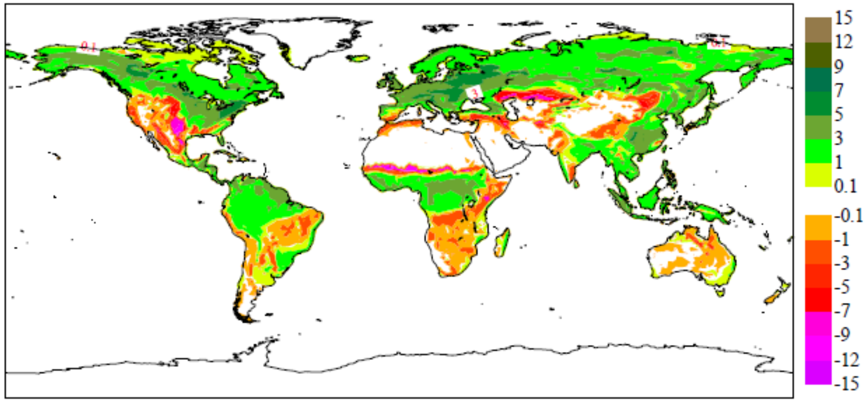


Preliminary results of CTESSEL with prognostic LAI detect anomalous years (here illustrating impact of the Russian heat-wave in July 2010) and have potential for vegetation growth monitoring

CTESSEL Net Ecosystem Exchange anomaly from 1979-2010 mean [micomoles/m2/s] for 201007



CTESSEL 1979-2010 monthly mean NEE [micromoles/m2/s] for 07



Outline

- Introduction: model development in NWP & Climate
- Land surface evolution and current status
- Natural biosphere CO_2 uptake in NWP framework
- Ongoing land research
- Conclusions

Land surface ongoing&future developments

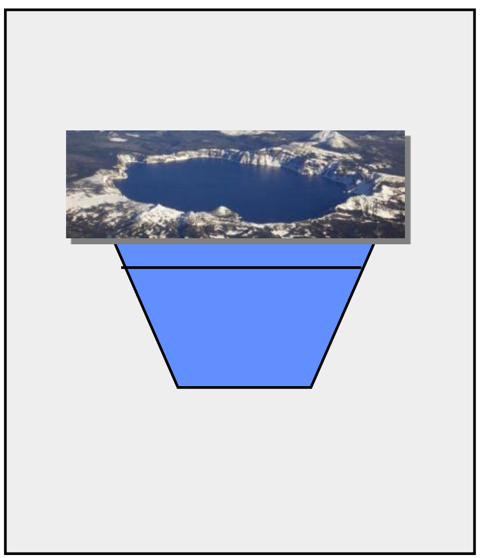
2012	2013-2015	2015-2020

- **FLake**

  Mironov et al (2010),
  Dutra et al. (2010),
  Balsamo et al. (2010)
  Balsamo et al. (2011)

  Extra tile (9) to account for sub-grid lakes

  Lake Climatology used in S4



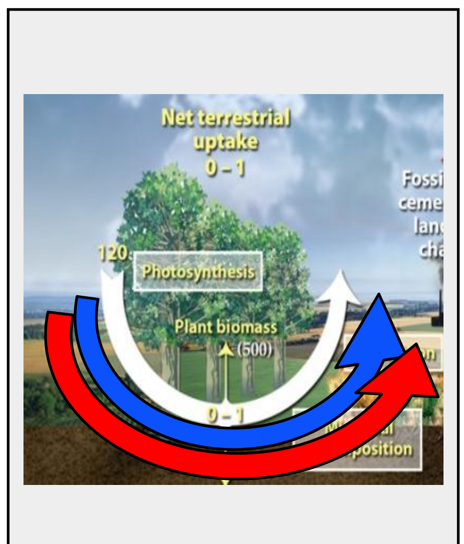
- **H_2O / E / CO_2**

  Carbon-driven vegetation

  scheme at the surface

  (FP7 & GMES funded)

  Boussetta et al. (2012 in prep.)

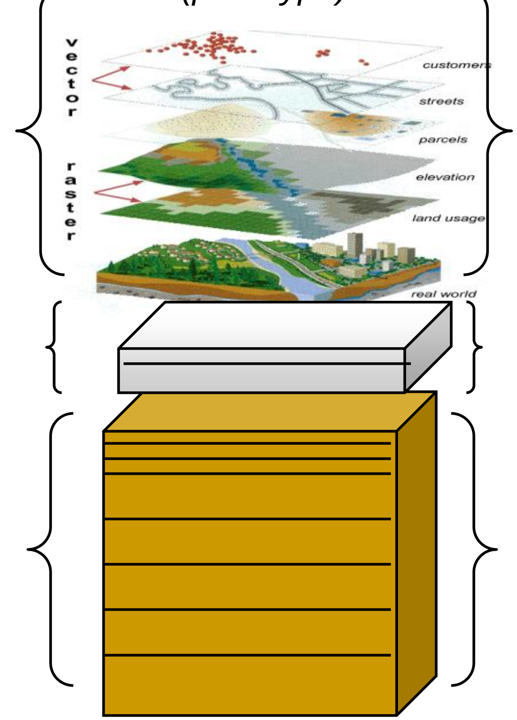


- Towards **Interactive Ecosystem** modelling

  to respond to several

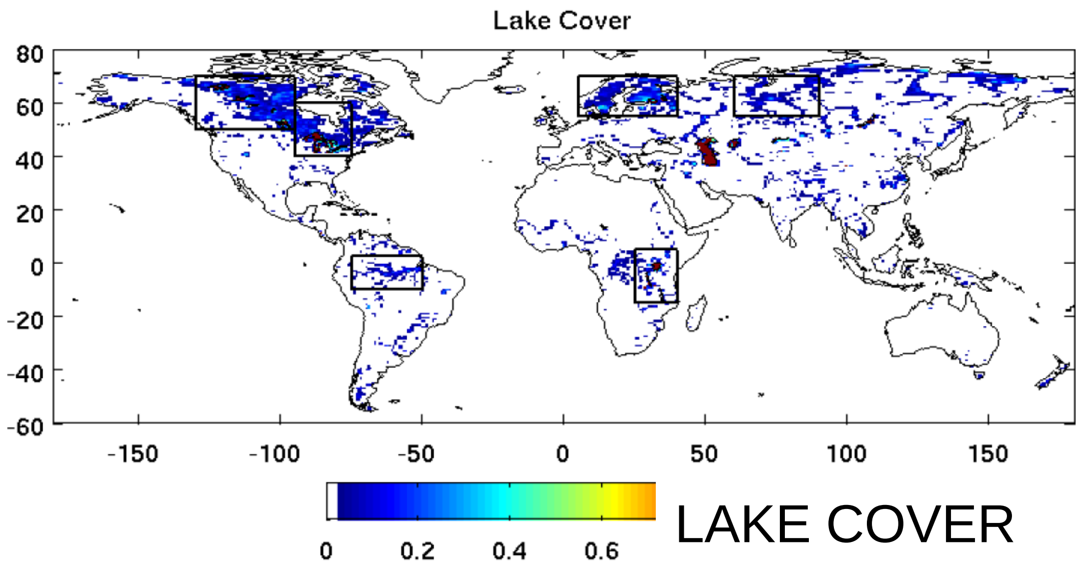
  applications needs

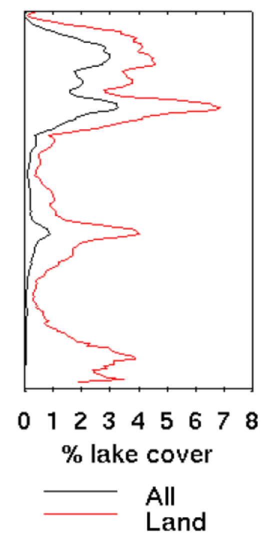
  (prototype)



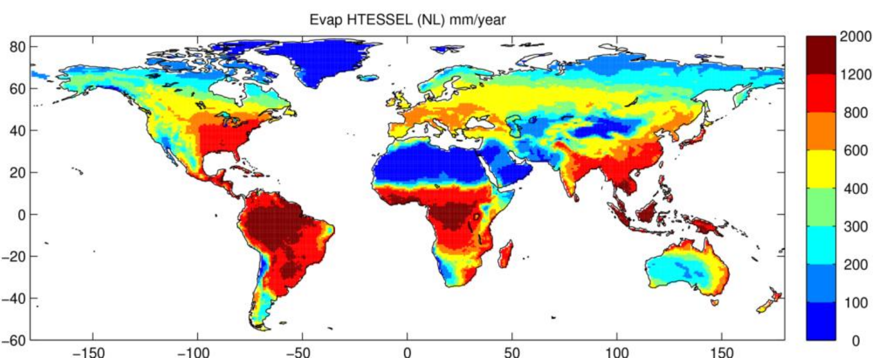
Lake modelling

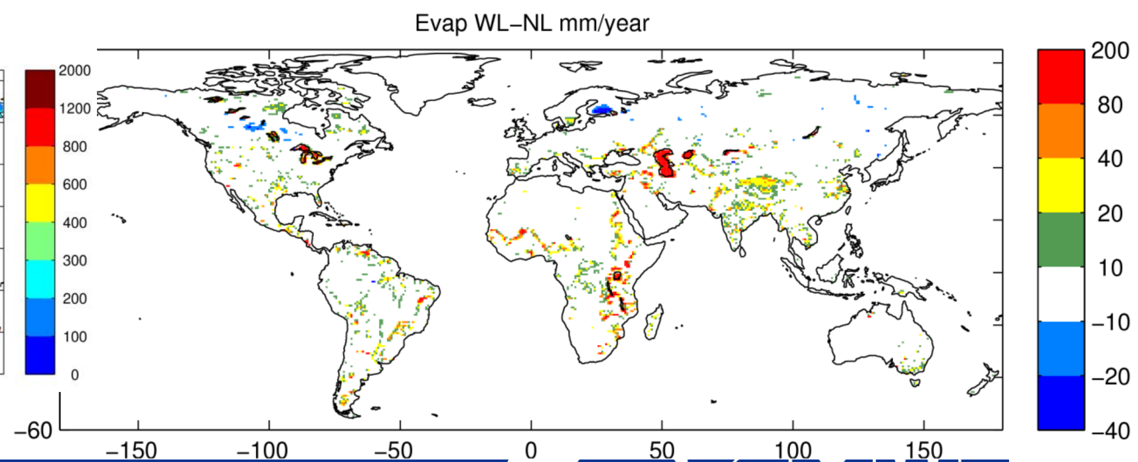
Dutra et al. (2009), Balsamo et al (2009), *Boreal Env. Res., and TM608/609*





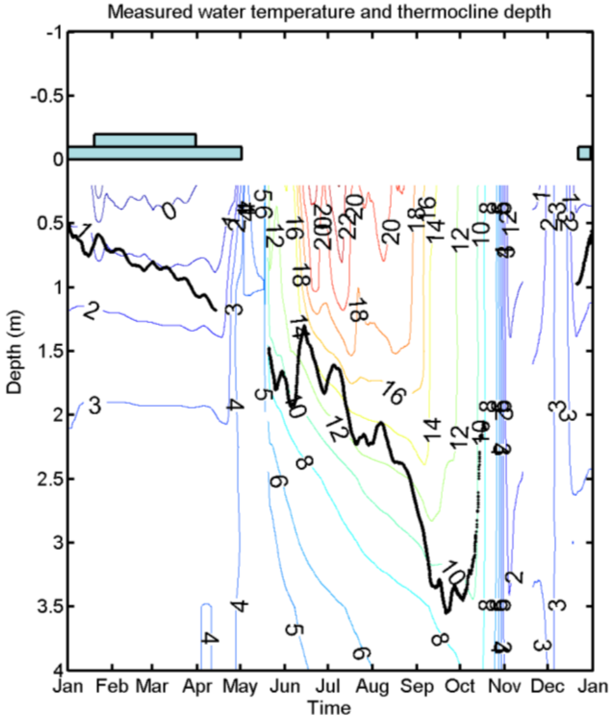
- FLAKE Lake model was tested in IFS CY35R3.
- Evaporation rates were increased in temperate climate
- L-band peak even stronger on lakes than SM!
- Crucial importance of lake depth

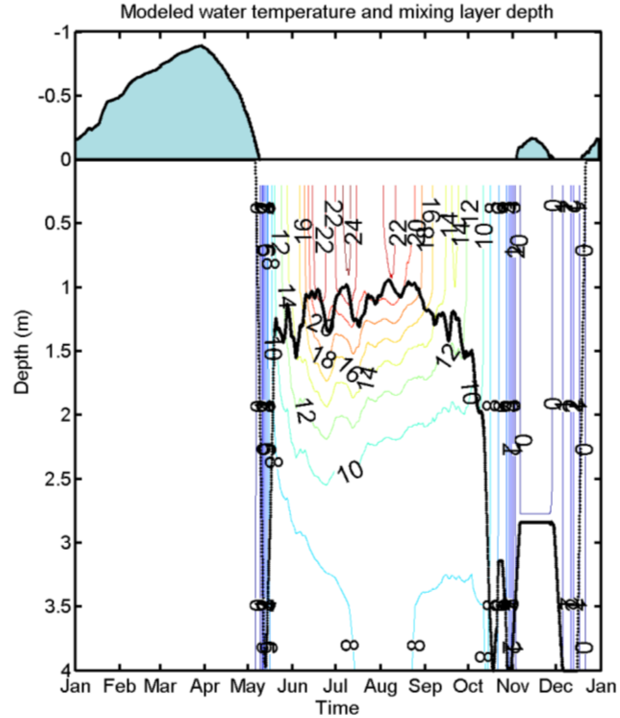




FLake model compared to Lake observations

Andrea Manrique-Sunen, Annika Nordbo (U. Helsinki), Ivan Mammarella (U. Helsinki)

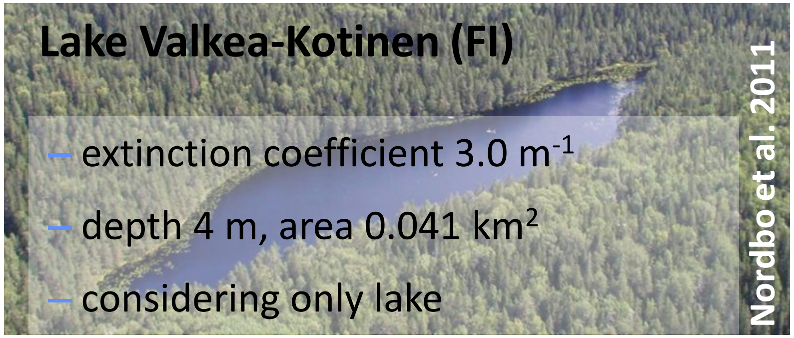




- Over a lake specialized site observations can be compared with FLake (Mironov et al. 2010) model output as provided by the LAKEHTESSEL model version (foreseen for 2012).

Courtesy of Annika Nordbo et al. (presented at EMS2011)

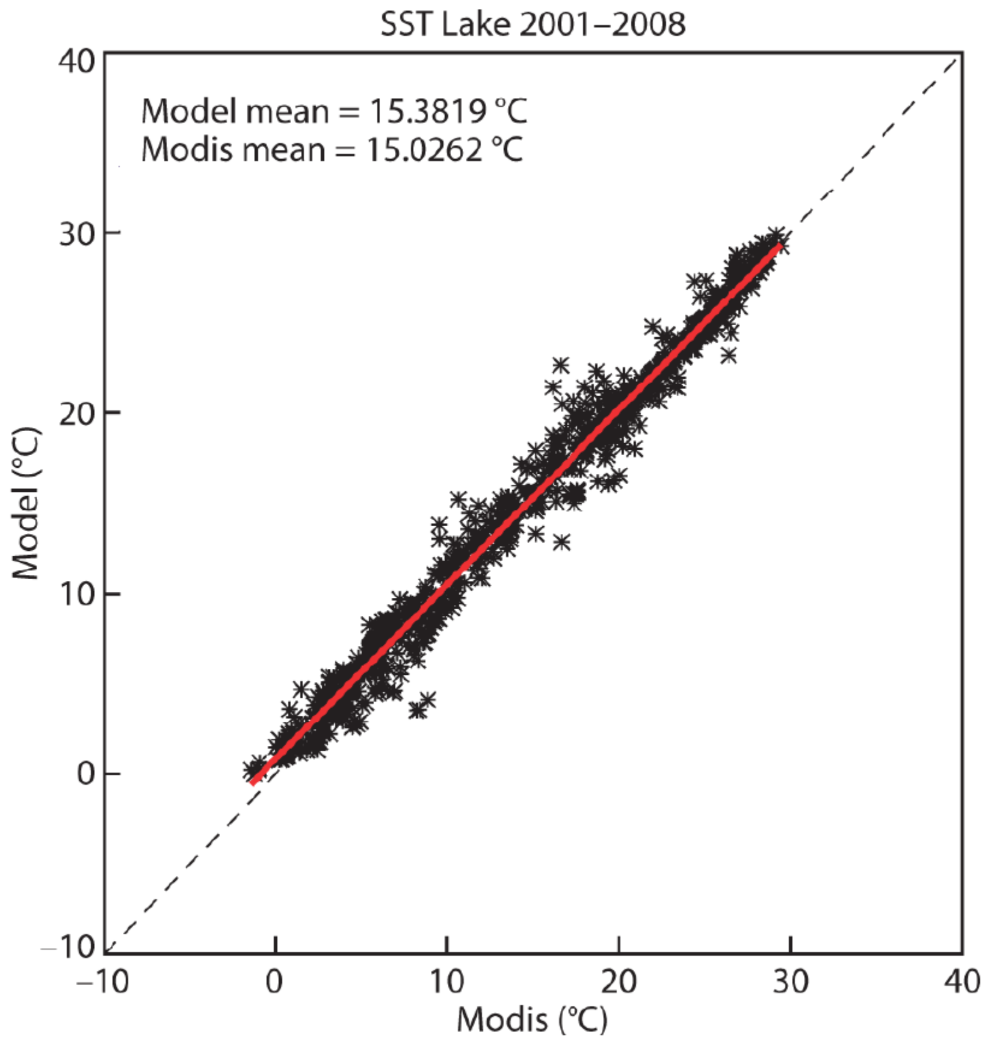
T_b varying with lake temperature [f (T_skin)]



ECMWF

FLake model in the IFS: global verification

Balsamo et al (2011) *ECMWF TM* **648**



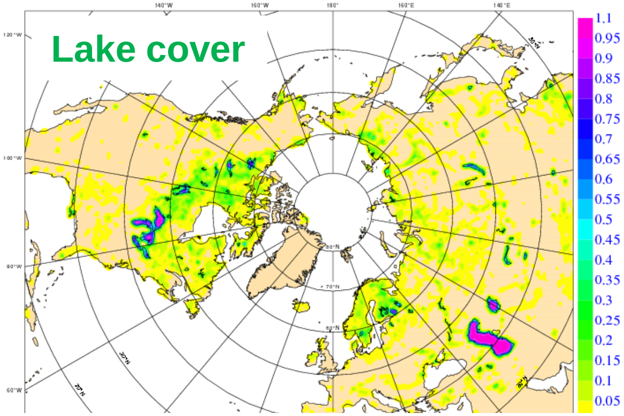
- FLAKE Lake surface temperature is verified against the MODIS LST product (from GSFC/NASA)
- Good correlation

  R=0.98
- Reduced bias

  BIAS (Mod-Obs) < 0.3 K

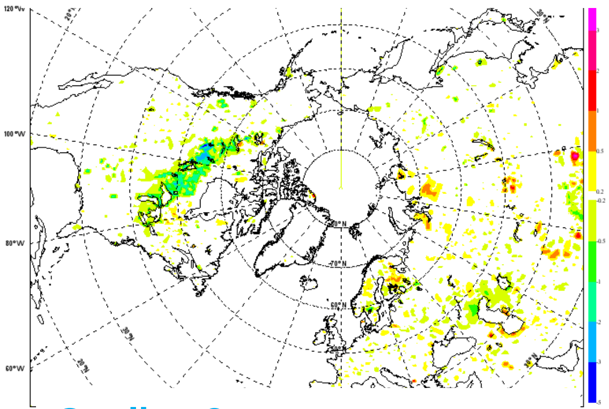
FLake model in the IFS: Forecast impact

Balsamo et al (2012) *TELLUS-A lake special issue 2012 (accepted)*



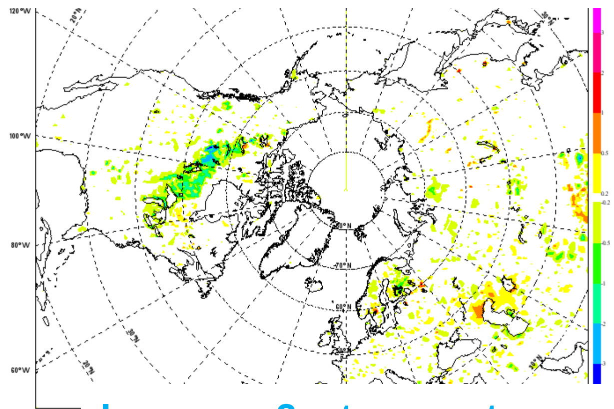
- **Offline surface runs are used to prepare ICs for a new lake modelling component and permit the forecast assessment. Those fields are adopted by S4 as new lake clim.**

Forecast sensitivity



Cooling 2m temperature
Warming 2m temperature

Forecast impact

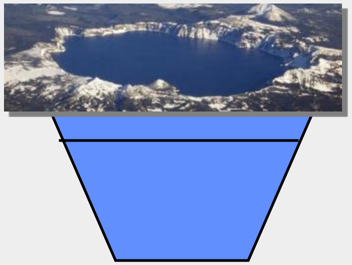


Improves 2m temperature
Degrades 2m temperature

- **FLake**

Mironov et al (2010),
Dutra et al. (2010),
Balsamo et al. (2010)
Balsamo et al. (2011)

Extra tile (9) to account for sub-grid lakes



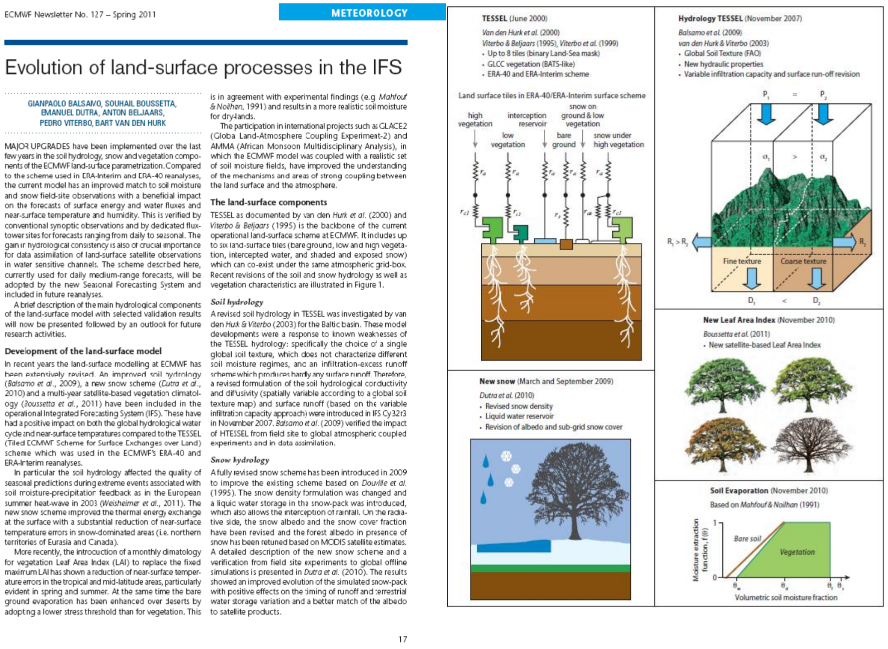
ERA-Interim forced runs of the FLAKE model are used to generate a lake model climatology which serves as IC in forecasts experiments (Here it is shown spring sensitivity and error impact on temperature when activating the lake model).

Conclusions and perspectives

- The current status of the operational land surface model and land data assimilation is summarized in the ECMWF Newsletter n. 127 [link].
- The land surface model development at ECMWF is moving towards Ecosystem modelling including Carbon Dioxide natural cycle as linked to Water and Energy.
- Several applications can benefit from the current land surface scheme (e.g. MACC/GAS, crop modelling, river modelling) and land surface benefits from a larger community of scientific users.
- Adding new modelling component extend the possibility of verification, monitoring and modelling, on the other hand the complexity of full-coupling needs care.
- Operational constraint and experience suggest that full-coupling between vegetation and atmosphere dynamics (via roughness) is subject to high sensitivity not fully understood.
- Similarly the photosynthesis-based algorithm is found to interact with low-level clouds and vertical diffusion and therefore carbon processes and evaporation processes have been made modular (Jarvis and Jacobs approaches co-existing)
- New developments in the land surface will focus on water bodies to improve the representation of natural microwave emission (C-band, L-band) for data assimilation

Thank you for your attention

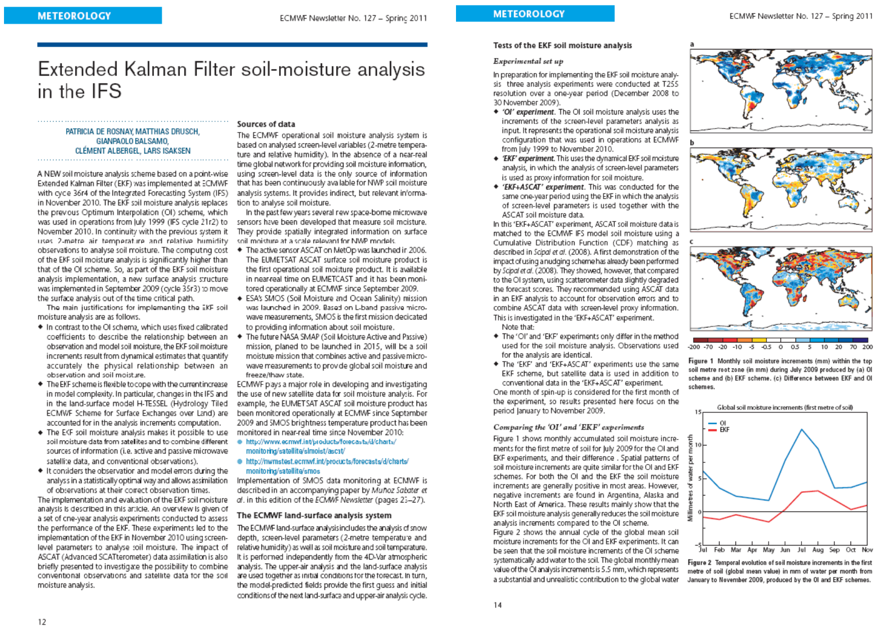
I'll be happy to respond to questions


ECMWF Newsletter No. 127 – Spring 2011

METEOROLOGY

Evolution of land-surface processes in the IFS

GIANPAOLO BALSAMO, SOUHAIL BOUSSETTA, EMANUEL DUTRA, ANTON BELJAARS, PEDRO VITERBO, BART VAN DEN HURK


METEOROLOGY

ECMWF Newsletter No. 127 – Spring 2011

Extended Kalman Filter soil-moisture analysis in the IFS

PATRICIA DE ROSNAY, MATTHIAS DRUSCH, GIANPAOLO BALSAMO, CLÉMENT ALBERGEL, LARS ISAKSEN

Recent dvances on Soil moisture, Snow, and Vegetation components of the IFS modelling and data assimilation are summarized in newsletter articles available at:

http://www.ecmwf.int/publications/newsletters/pdf/127.pdf

ECMWF